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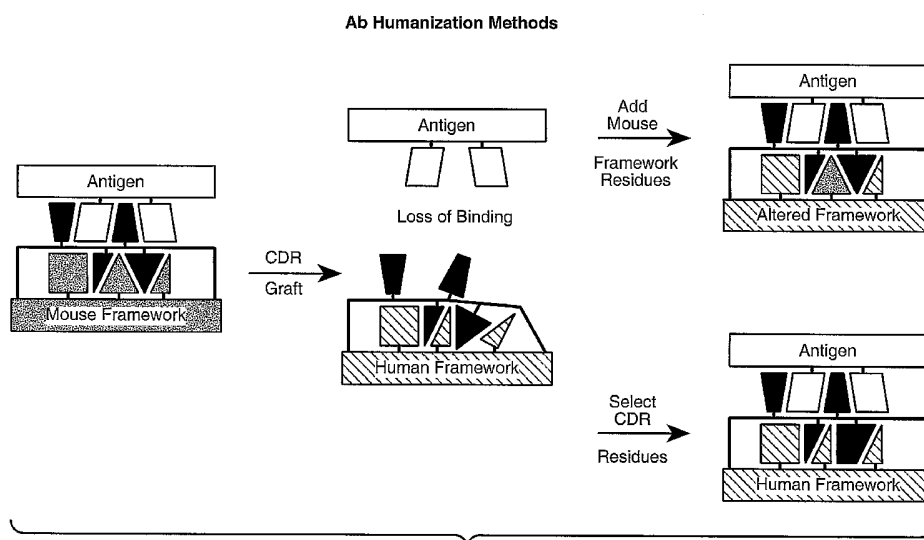
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(54) Title: CDR-REPAIRED ANTIBODIES



(57) Abstract: The present application concerns restoring antigen binding during humanization of antibodies through the selection of repaired hypervariable regions rather than through framework changes.

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CDR-REPAIRED ANTIBODIES

This is a non-provisional application claiming priority under 35 USC §119 to provisional application no. 60/545,840 filed February 19, 2004, the entire disclosure of which is hereby incorporated by reference.

Field of the Invention

The present invention concerns restoring antigen binding during humanization of antibodies through the selection of repaired hypervariable regions rather than through framework changes.

Background of the Invention

Many potentially interesting monoclonal antibodies can rapidly be produced by the mouse immune system for biological study. In a clinical setting however, the use of these murine antibodies can result in a human anti-mouse antibody response (HAMA) thus negating their utility. A method to transfer the murine antigen binding information to a non-immunogenic human antibody acceptor, a process known as humanization, has resulted in many therapeutically useful drugs. The method of humanization generally begins by transferring all six murine complementarity determining regions (CDRs) onto a human antibody framework (Jones *et al.*, *Nature* **321**, 522-525 (1986)). These CDR-grafted antibodies generally do not retain their original affinity for antigen binding, and in fact, affinity is often severely impaired. Besides the CDRs, select non-human antibody framework residues must also be incorporated to maintain proper CDR conformation (Chothia *et al.*, *Nature* **342**:877 (1989)). The transfer of key mouse framework residues to the human acceptor in order to support the structural conformation of the grafted CDRs has been shown to restore antigen binding and affinity (Riechmann *et al.*, *J. Mol. Biol.* **224**, 487-499

(1992); Foote and Winter, *J. Mol. Biol.* 224:487-499 (1992); Presta et al., *J. Immunol.* 151, 2623-2632 (1993); Werther et al., *J. Immunol. Methods* 157:4986-4995 (1996); and Presta et al., *Thromb. Haemost.* 85:379-389 (2001)). Many of the framework positions that are likely to affect affinity have been identified, thus structural modeling to select new residues in a stepwise fashion can generally lead to variants with restored antigen binding. Alternatively, phage antibody libraries targeted at these residues can also be used to enhance and speed up the affinity maturation process (Wu et al., *J. Mol. Biol.* 294:151-162 (1999) and Wu, H., *Methods in Mol. Biol.* 207:197-212 (2003)).

Two approaches have been taken when choosing a starting human acceptor. One approach compares the sequence of the murine antibody to a list of known human antibody sequences in order to choose the human antibody most homologous to the murine antibody (Shearman et al., *J. Immunol.* 147:4366 (1991); Kettleborough et al., *Protein Eng.* 4, 773 (1991); Tempest et al., *Biotechnology* 9:266 (1991); Co et al., *Proc. Natl. Acad. Sci. USA* 88:2869 (1991); Routledge et al., *Eur. J. Immunol.* 21:2717 (1991)). This approach is designed to reduce the likelihood of disrupting the integrity of the CDRs upon grafting them onto the new human acceptor. A second approach utilizes a consensus human framework derived from human VL and VH subgroups. By choosing the most frequently used sequence as a acceptor, this approach has been shown to reduce the potential of an immunological response to the humanized antibody (Presta et al., *J. Immunol.* 151:2623-2632 (1993)). Following transfer of CDR residues into an acceptor chosen by either of these methods, it has been necessary to alter framework residues in the acceptor in order to restore and enhance antigen binding affinity.

Humanized anti-IgE, anti-CD11a and anti-tissue factor (TF) antibodies have been described in Presta et al., *J. Immunol.* 151, 2623-2632 (1993), Werther et al., *J. Immunol. Methods* 157:4986-4995 (1996), and Presta et al., *Thromb. Haemost.* 85:379-389 (2001), respectively.

Patent publications describing humanized antibody variants include US Patent No. 6,407,213 and WO92/22653 (Carter and

Presta), WO98/45332 (Wells et al.), WO98/45331 (Baca et al.), as well as US2003/0228663A1 and WO03/087131A2 (Lowman et al.).

US 2004/0162413, Watkins et al., published August, 2004 refers to methods of optimizing antibody variable region binding affinity. WO03/105782 A2, Rybak et al., published December 2003, references specificity grafting of a murine antibody onto a human framework.

SUMMARY OF THE INVENTION

Molecular interactions between hypervariable regions and the old framework are often lost upon grafting hypervariable regions onto a new framework, resulting in a perturbation of these hypervariable regions and a loss in antigen binding affinity. Rather than transferring murine residues that interact with the hypervariable region(s) to the new framework, the present application demonstrates that the molecular fit between the new framework and the grafted hypervariable region can be restored by changing residues residing within the hypervariable region(s). Utilizing a phage library designed to maintain a sequence bias towards the grafted hypervariable regions, mutations were introduced into all six hypervariable regions and clones with high antigen binding affinity, but lacking any framework changes, were selected. In this application, it is demonstrated that high affinity binding can rapidly be restored through slight modifications to murine hypervariable regions grafted to a human acceptor without any changes to framework residues.

Accordingly, in a first aspect, the invention concerns an altered antibody which binds an antigen with a binding affinity (K_d) value of no more than about 5×10^{-7} M, the altered antibody comprising variable heavy (VH) and variable light (VL) acceptor human frameworks and one or more altered hypervariable regions derived from a non-human antibody which binds the antigen, wherein the VH and VL frameworks lack human to non-human amino acid substitutions therein.

Various forms of the altered antibody are contemplated herein. For example, the altered antibody may be an intact antibody (e.g. a human IgG1 antibody) or an antibody fragment (e.g. a Fab or $F(ab')_2$). Furthermore, the altered antibody may be labeled with a detectable label, immobilized on a solid phase

and/or conjugated with a heterologous compound (such as a cytotoxic agent).

Diagnostic uses for the altered antibody are contemplated. In one diagnostic application, the invention provides a method for
5 determining the presence of an antigen of interest comprising exposing a sample suspected of containing the antigen to the altered antibody and determining binding of the altered antibody to the sample. For this use, the invention provides a kit comprising the altered antibody and instructions for using the
10 altered antibody to detect the antigen.

The invention further provides: isolated nucleic acid encoding the altered antibody; a vector comprising the nucleic acid, optionally, operably linked to control sequences recognized by a host cell transformed with the vector; a host cell
15 transformed with the nucleic acid; a process for producing the altered antibody comprising culturing the host cell so that the nucleic acid is expressed and, optionally, recovering the altered antibody from the host cell culture (e.g. from the host cell culture medium).

20 The invention also provides a composition comprising the altered antibody and a pharmaceutically acceptable carrier or diluent. This composition for therapeutic use is sterile and may be lyophilized.

The invention further provides a method for treating a mammal
25 comprising administering an effective amount of the altered antibody to the mammal.

In addition, the invention provides a method of making an altered antibody comprising incorporating non-human hypervariable region residues into an acceptor human framework and further
30 comprising introducing one or more amino acid substitutions in one or more hypervariable regions, without modifying the acceptor human framework sequence, and selecting an antibody with a binding affinity (K_d) value of no more than about 5×10^{-7} M.

Moreover, the invention provides a method of mutating a
35 nucleic acid sequence comprising:

(a) annealing from about two to about 20 oligonucleotides to a single stranded nucleic acid template, wherein the oligonucleotide:template ratio for each oligonucleotide is greater

than 1;

(b) removing excess unannealed oligonucleotides; and

(c) filling in a nucleic acid strand which is complementary to the template.

5 In yet a further aspect, the invention provides a method of selecting an altered antibody comprising:

(a) preparing nucleic acid encoding at least the variable heavy (VH) and variable light (VL) domains of an antibody, each comprising an acceptor human framework and hypervariable regions
10 of a non-human antibody;

(b) substituting hypervariable region residues by introducing an approximately 10-50 percent mutation rate into the nucleic acid so as to maintain a bias towards the non-human hypervariable region sequences; and

15 (c) selecting one or more altered antibodies that bind antigen.

Brief Description of the Drawings

Figures 1A-1B depict amino acid sequences of the acceptor human consensus framework and the murine monoclonal antibodies: MHM24
20 (which binds CD11a), Mae11 (which binds IgE) and D3 (which binds tissue factor, TF). Numbering is according to Kabat et al. (Kabat et al., *Sequences of Proteins of Immunological Interest*, 5th Ed., Public Health Service, National Institutes of Health, Bethesda, MD (1991)). The extended hypervariable regions are boxed. Differences
25 between the acceptor human consensus framework and the human consensus sequence of the Kabat heavy chain subgroup III are in bold. These include R71A, N73T, and L78A (Carter et al., *Proc. Natl. Acad. Sci. USA* 89:4285 (1992)). For the library design and direct hypervariable region grafts, the hypervariable regions were
30 L1 (24-34), L2 (50-56), L3 (89-97), H1 (26-35a), H2 (49-65), H3 (93-102). The diversity in positions 49 and 94 was limited to A, G, S and T for position 49 and R or K for position 94.

Figure 2 shows affect of reagent (PB) on DNA binding to silica. The binding of plasmid DNA (Δ), single stranded template DNA ($\bullet$),
35 and an 81 base pair oligonucleotide ($\blacksquare$) to a silica column was monitored by A260 as a function of the amount of reagent (PB) added. The silica column and PB reagent were obtained from a

QIAQUICK PCR purification kit (Qiagen kit 28106).

Figures 3A-1, 3A-2, 3B-1, 3B-2, 3C-1 and 3C-2 represent distribution and sequence of hypervariable regions replaced during mutagenesis using 6 oligonucleotides. Hypervariable region sequences from the initial Fab displayed phage libraries designed for humanization of the murine monoclonal antibodies D3 (Figs. 3A-1 and 3A-2), MHM24 (Figs. 3B-1 and 3B-2) and Mae11 (Figs. 3C-1 and 3C-2) are shown. The hypervariable region sequences of the original murine antibodies are boxed. Hypervariable regions that were not replaced during the mutagenesis are shown in bold. Each hypervariable region in each library was replaced approximately 50 percent of the time. The sequence of the hypervariable regions that were replaced during mutagenesis reflects a bias towards the original murine hypervariable region sequence.

Figures 4A-4B depict sequence analysis and phage ELISA affinities of clones following selection on antigen. Partial sequences are shown for clones selected for binding to IgE (sequences in H1), LFA-1 (sequences in L2) and TF (sequences in L1, L2 or L3). Additional sequence changes in the VL or VH domains observed in regions outside these areas are noted. Amino acids identical to the direct hypervariable region grafted sequence are shaded and the hypervariable regions are boxed. The number of siblings of identical DNA sequence and the affinity of each clone as determined by phage ELISA is noted. From the Mae11 humanization library, 60 complete sequences were analyzed; 33 and 49 complete sequences were analyzed for the MHM24 and D3 humanization libraries, respectively. The affinity of the direct hypervariable region grafted variants were 4 and 20 nM for the MHM24 and D3 grafted variants, respectively. No detectable binding was observed with the Mae11 hypervariable region grafted variant.

Figure 5 depicts schematically a comparison between prior humanization techniques (upper right), and the present method for making "CDR-repaired" antibodies (lower right).

Figures 6A-6B depict exemplary acceptor human consensus framework sequences for use in practicing the instant invention with sequence identifiers as follows:

Variable heavy (VH) consensus frameworks

- human VH subgroup I consensus framework minus Kabat CDRs (SEQ ID NO:23)
- human VH subgroup I consensus framework minus extended
- 5 hypervariable regions (SEQ ID NOs:24-26)
- human VH subgroup II consensus framework minus Kabat CDRs (SEQ ID NO:27)
- human VH subgroup II consensus framework minus extended
- hypervariable regions (SEQ ID NOs:28-30)
- 10 human VH subgroup II consensus framework minus extended
- human VH subgroup III consensus framework minus Kabat CDRs (SEQ ID NO:31)
- human VH subgroup III consensus framework minus extended
- hypervariable regions (SEQ ID NOs:32-34)
- 15 human VH acceptor framework minus Kabat CDRs (SEQ ID NO:35)
- human VH acceptor framework minus extended hypervariable regions (SEQ ID NOs:36-37)
- human VH acceptor 2 framework minus Kabat CDRs (SEQ ID NO:38)
- human VH acceptor 2 framework minus extended hypervariable regions
- 20 (SEQ ID NOs:39-41)

Variable light (VL) consensus frameworks

- human VL kappa subgroup I consensus framework (SEQ ID NO:42)
- human VL kappa subgroup II consensus framework (SEQ ID NO:43)
- human VL kappa subgroup III consensus framework (SEQ ID NO:44)
- 25 human VL kappa subgroup IV consensus framework (SEQ ID NO:45)

Detailed Description of the Preferred Embodiments**I. Definitions**

- 30 The present application uses "variable domain residue numbering as in Kabat" which refers to the numbering system used for heavy chain variable domains or light chain variable domains of the compilation of antibodies in Kabat et al., Sequences of Proteins of Immunological Interest, 5th Ed. Public Health Service,
- 35 National Institutes of Health, Bethesda, MD. (1991). Using this numbering system, the actual linear amino acid sequence may contain fewer or additional amino acids corresponding to a

shortening of, or insertion into, a FR or CDR of the variable domain. For example, a heavy chain variable domain may include a single amino acid insert (residue 52a according to Kabat) after residue 52 of H2 and inserted residues (e.g. residues 82a, 82b, and 82c, etc according to Kabat) after heavy chain FR residue 82. The Kabat numbering of residues may be determined for a given antibody by alignment at regions of homology of the sequence of the antibody with a "standard" Kabat numbered sequence.

A "non-human antibody" is an antibody comprising variable domain sequences from a non-human species. Preferred non-human antibodies are rodent or murine antibodies. Such antibodies are generally made by immortalization of a non-human B cell, e.g. via hybridoma technology.

An "altered antibody" herein is an antibody comprising variable light (VL) and variable heavy (VH) amino acid sequences which differ from a naturally occurring antibody amino acid sequence.

An "antigen" is a predetermined antigen to which an antibody can selectively bind. The target antigen may be polypeptide, carbohydrate, nucleic acid, lipid, hapten or other naturally occurring or synthetic compound. Preferably, the target antigen is a polypeptide.

An "acceptor human framework" for the purposes herein is a framework comprising the amino acid sequence of a VL or VH framework derived from a human immunoglobulin framework, or from a human consensus framework.

An acceptor human framework "derived from" a human immunoglobulin framework or human consensus framework may comprise the same amino acid sequence thereof, or may contain pre-existing amino acid sequence changes. Where pre-existing amino acid changes are present, preferably no more than 5 and preferably 4 or less, or 3 or less, pre-existing amino acid changes are present. Where pre-existing amino acid changes are present in a VH, preferably those changes are only at positions four, three or less of 71H, 73H, 78H and 93H (if the framework includes position 93H); for instance, the amino acid residues at those positions may be 71A, 73T, 78A, and/or 93S. Preferably, the VL acceptor human

framework is identical in sequence to the VL human immunoglobulin framework sequence or human consensus framework sequence.

A "human consensus framework" is a framework which represents the most commonly occurring amino acid residue in a selection of human immunoglobulin VL or VH framework sequences. Preferably the selection of human immunoglobulin VL or VH sequences is from a subgroup of variable domain sequences. Preferably, the subgroup of sequences is a subgroup as in Kabat et al. For the VL, the most preferred subgroup is subgroup kappa I as in Kabat et al. As to VH, the most preferred subgroup is subgroup III as in Kabat et al.

A "VH subgroup III consensus framework" comprises the consensus sequence obtained from the amino acid sequences in variable heavy subgroup III of Kabat et al. Preferably, the VH subgroup III consensus framework amino acid sequence comprises: EVQLVESGGGLVQPGGSLRLSCAAS (SEQ ID NO:1)-**H1**-WVRQAPGKGLEWV (SEQ ID NO:2)-**H2**-RFTISRDNKNTLYLQMNSLRAEDTAVYYC (SEQ ID NO:3)-**H3**-WGQGTLLVTVSS (SEQ ID NO:4).

A "VL subgroup I consensus framework" comprises the consensus sequence obtained from the amino acid sequences in variable light kappa subgroup I of Kabat et al. Preferably, the VL subgroup I consensus framework amino acid sequence comprises: DIQMTQSPSSLSASVGDRVTITC (SEQ ID NO:5)-**L1**-WYQQKPGKAPKLLIY (SEQ ID NO:6)-**L2**-GVPSRFSGSGSGTDFTLTISSLQPEDFATYYC (SEQ ID NO:7)-**L3**-FGQGTKVEIK (SEQ ID NO:8).

An "unmodified human framework" is a human framework which has the same amino acid sequence as the acceptor human framework, e.g. lacking human to non-human amino acid substitution(s) in the acceptor human framework.

An "altered hypervariable region" for the purposes herein is a hypervariable region comprising one or more (e.g. one to about 16) amino acid substitution(s) therein.

An "un-modified hypervariable region" for the purposes herein is a hypervariable region having the same amino acid sequence as a non-human antibody from which it was derived, i.e. one which lacks one or more amino acid substitutions therein.

The term "antibody" is used in the broadest sense and

specifically covers monoclonal antibodies (including intact antibodies), polyclonal antibodies, multispecific antibodies (e.g., bispecific antibodies), and antibody fragments so long as they exhibit the desired biological activity.

5 The term "hypervariable region" when used herein refers to the regions of an antibody variable domain which are hypervariable in sequence and/or form structurally defined loops. Generally, antibodies comprise six hypervariable regions; three in the VH (H1, H2, H3), and three in the VL (L1, L2, L3). A number of
10 hypervariable region delineations are in use and are encompassed herein. The Kabat Complementarity Determining Regions (CDRs) are based on sequence variability and are the most commonly used (Kabat et al., *Sequences of Proteins of Immunological Interest*, 5th Ed. Public Health Service, National Institutes of Health,
15 Bethesda, MD. (1991)). Chothia refers instead to the location of the structural loops (Chothia and Lesk *J. Mol. Biol.* 196:901-917 (1987)). The AbM hypervariable regions represent a compromise between the Kabat CDRs and Chothia structural loops, and are used by Oxford Molecular's AbM antibody modeling software. The
20 "contact" hypervariable regions are based on an analysis of the available complex crystal structures. The residues from each of these hypervariable regions are noted below.

	Loop	Kabat	AbM	Chothia	Contact
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25	L1	L24-L34	L24-L34	L26-L32	L30-L36
	L2	L50-L56	L50-L56	L50-L52	L46-L55
	L3	L89-L97	L89-L97	L91-L96	L89-L96
	H1	H31-H35B	H26-H35B	H26-H32...34	H30-H35B
		(Kabat Numbering)			
30	H1	H31-H35	H26-H35	H26-H32	H30-H35
		(Chothia Numbering)			
	H2	H50-H65	H50-H58	H53-H55	H47-H58
	H3	H95-H102	H95-H102	H96-H101	H93-H101

35 Hypervariable regions may comprise "extended hypervariable regions" as follows: 24-34 (L1), 50-56 or 49-56 (L2) and 89-97 (L3) in the VL and 26-35, 26-35A or 26-35B(H1), 50-65 or 49-65

(H2) and 93-102, 94-102 or 95-102 (H3) in the VH. The variable domain residues are numbered according to Kabat *et al.*, *supra* for each of these definitions.

"Framework" or "FR" residues are those variable domain
5 residues other than the hypervariable region residues as herein defined.

"Antibody fragments" comprise a portion of a full length antibody, generally the antigen binding or variable region thereof. Examples of antibody fragments include Fab, Fab',
10 F(ab')₂, and Fv fragments; diabodies; linear antibodies; single-chain antibody molecules; and multispecific antibodies formed from antibody fragments.

An "intact antibody" herein is one comprising a VL and VH domains, as well as complete light and heavy chain constant
15 domains.

A "human IgG1" antibody herein comprises constant region sequences of a human IgG1 antibody.

The term "monoclonal antibody" as used herein refers to an antibody obtained from a population of substantially homogeneous
20 antibodies, *i.e.*, the individual antibodies comprising the population are identical and/or bind the same epitope except for possible variants that may arise during production of the monoclonal antibody, such variants generally being present in minor amounts. In contrast to conventional (polyclonal) antibody
25 preparations which typically include different antibodies directed against different determinants (epitopes), each monoclonal antibody is directed against a single determinant on the antigen. The modifier "monoclonal" indicates the character of the antibody as being obtained from a substantially homogeneous population of
30 antibodies, and is not to be construed as requiring production of the antibody by any particular method. For example, the monoclonal antibodies to be used in accordance with the present invention may be made by the hybridoma method first described by Kohler *et al.*, *Nature* 256:495 (1975), or may be made by
35 recombinant DNA methods (see, *e.g.*, U.S. Patent No. 4,816,567). The "monoclonal antibodies" may also be isolated from phage antibody libraries using the techniques described in Clackson *et*

al., *Nature* 352:624-628 (1991) and Marks *et al.*, *J. Mol. Biol.* 222:581-597 (1991), for example.

The monoclonal antibodies herein specifically include "chimeric" antibodies (immunoglobulins) in which a portion of the heavy and/or light chain is identical with or homologous to corresponding sequences in antibodies derived from a particular species or belonging to a particular antibody class or subclass, while the remainder of the chain(s) is identical with or homologous to corresponding sequences in antibodies derived from another species or belonging to another antibody class or subclass, as well as fragments of such antibodies, so long as they exhibit the desired biological activity (U.S. Patent No. 4,816,567; and Morrison *et al.*, *Proc. Natl. Acad. Sci. USA* 81:6851-6855 (1984)).

"Humanized" forms of non-human (e.g., murine) antibodies are chimeric antibodies which contain minimal sequence derived from non-human immunoglobulin. For the most part, humanized antibodies are human immunoglobulins (recipient antibody) in which residues from a hypervariable region of the recipient are replaced by residues from a hypervariable region of a non-human species (donor antibody) such as mouse, rat, rabbit or nonhuman primate having the desired specificity, affinity, and capacity. In some instances, Fv framework region (FR) residues of the human immunoglobulin are replaced by corresponding non-human residues. Furthermore, humanized antibodies may comprise residues which are not found in the recipient antibody or in the donor antibody. These modifications are made to further refine antibody performance. In general, the humanized antibody will comprise substantially all of at least one, and typically two, variable domains, in which all or substantially all of the hypervariable loops correspond to those of a non-human immunoglobulin and all or substantially all of the FR regions are those of a human immunoglobulin sequence, except for possible FR substitution(s) as noted above. The humanized antibody optionally also will comprise at least a portion of an immunoglobulin constant region, typically a human immunoglobulin Fc region. For further details, see Jones *et al.*, *Nature* 321:522-525 (1986); Riechmann *et al.*, *Nature*

332:323-329 (1988); and Presta, *Curr. Op. Struct. Biol.* 2:593-596 (1992).

A "human antibody" is one which possesses an amino acid sequence which corresponds to that of an antibody produced by a human and/or has been made using any of the techniques for making human antibodies as disclosed herein. Human antibodies can be produced using various techniques known in the art. In one embodiment, the human antibody is selected from a phage library, where that phage library expresses human antibodies (Vaughan et al. *Nature Biotechnology* 14:309-314 (1996); Sheets et al. *PNAS (USA)* 95:6157-6162 (1998)); Hoogenboom and Winter, *J. Mol. Biol.*, 227:381 (1991); Marks et al., *J. Mol. Biol.*, 222:581 (1991)). Human antibodies can also be made by introducing human immunoglobulin loci into transgenic animals, e.g., mice in which the endogenous immunoglobulin genes have been partially or completely inactivated. Upon challenge, human antibody production is observed, which closely resembles that seen in humans in all respects, including gene rearrangement, assembly, and antibody repertoire. This approach is described, for example, in U.S. Patent Nos. 5,545,807; 5,545,806; 5,569,825; 5,625,126; 5,633,425; 5,661,016, and in the following scientific publications: Marks et al., *Bio/Technology* 10: 779-783 (1992); Lonberg et al., *Nature* 368: 856-859 (1994); Morrison, *Nature* 368:812-13 (1994); Fishwild et al., *Nature Biotechnology* 14: 845-51 (1996); Neuberger, *Nature Biotechnology* 14: 826 (1996); Lonberg and Huszar, *Intern. Rev. Immunol.* 13:65-93 (1995). Alternatively, the human antibody may be prepared via immortalization of human B lymphocytes producing an antibody directed against a target antigen (such B lymphocytes may be recovered from an individual or may have been immunized *in vitro*). See, e.g., Cole et al., *Monoclonal Antibodies and Cancer Therapy*, Alan R. Liss, p. 77 (1985); Boerner et al., *J. Immunol.*, 147 (1):86-95 (1991); and US Pat No. 5,750,373.

"Single-chain Fv" or "sFv" antibody fragments comprise the V_H and V_L domains of antibody, wherein these domains are present in a single polypeptide chain. Generally, the sFv polypeptide further comprises a polypeptide linker between the V_H and V_L domains which

enables the sFv to form the desired structure for antigen binding. For a review of sFv see Pluckthun in *The Pharmacology of Monoclonal Antibodies*, vol. 113, Rosenberg and Moore eds. Springer-Verlag, New York, pp. 269-315 (1994).

5 The term "diabodies" refers to small antibody fragments with two antigen-binding sites, which fragments comprise a heavy chain variable domain (V_H) connected to a light chain variable domain (V_L) in the same polypeptide chain ($V_H - V_L$). By using a linker that is too short to allow pairing between the two domains on the same chain, the domains are forced to pair with the complementary domains of another chain and create two antigen-binding sites. Diabodies are described more fully in, for example, EP 404,097; WO 93/11161; and Hollinger et al., *Proc. Natl. Acad. Sci. USA* 90:6444-6448 (1993).

15 The expression "linear antibodies" when used throughout this application refers to the antibodies described in Zapata et al. *Protein Eng.* 8(10):1057-1062 (1995). Briefly, these antibodies comprise a pair of tandem Fd segments ($V_H - C_{H1} - V_H - C_{H1}$) which form a pair of antigen binding regions. Linear antibodies can be bispecific or monospecific.

20 An "amino acid substitution" refers to the replacement of an existing amino acid residue in a predetermined amino acid sequence with another different amino acid residue.

25 An "isolated" antibody is one which has been identified and separated and/or recovered from a component of its natural environment. Contaminant components of its natural environment are materials which would interfere with diagnostic or therapeutic uses for the antibody, and may include enzymes, hormones, and other proteinaceous or nonproteinaceous solutes. In preferred embodiments, the antibody will be purified (1) to greater than 95% by weight of antibody as determined by the Lowry method, and most preferably more than 99% by weight, (2) to a degree sufficient to obtain at least 15 residues of N-terminal or internal amino acid sequence by use of a spinning cup sequenator, or (3) to

35 homogeneity by SDS-PAGE under reducing or nonreducing conditions using Coomassie blue or, preferably, silver stain. Isolated

antibody includes the antibody *in situ* within recombinant cells since at least one component of the antibody's natural environment will not be present. Ordinarily, however, isolated antibody will be prepared by at least one purification step.

5 "Treatment" refers to both therapeutic treatment and prophylactic or preventative measures. Those in need of treatment include those already with the disorder as well as those in which the disorder is to be prevented.

A "disorder" is any condition that would benefit from
10 treatment with the altered antibody. This includes chronic and acute disorders or diseases including those pathological conditions which predispose the mammal to the disorder in question.

The term "CD11a" when used herein refers to the alpha subunit
15 of LFA-1 from any mammal, but preferably from a human. The CD11a may be isolated from a natural source of the molecule or may be produced by synthetic means (e.g., using recombinant DNA technology.) The amino acid sequence for human CD11a is described in EP 362 526B1, for example.

20 The term "LFA-1-mediated disorder" refers to a pathological state caused by cell adherence interactions involving the LFA-1 receptor on lymphocytes. Examples of such disorders include T cell inflammatory responses such as inflammatory skin diseases including psoriasis; responses associated with inflammatory bowel
25 disease (such as Crohn's disease and ulcerative colitis); adult respiratory distress syndrome; dermatitis; meningitis; encephalitis; uveitis; allergic conditions such as eczema and asthma; conditions involving infiltration of T cells and chronic inflammatory responses; skin hypersensitivity reactions (including
30 poison ivy and poison oak); atherosclerosis; leukocyte adhesion deficiency; autoimmune diseases such as rheumatoid arthritis, systemic lupus erythematosus (SLE), diabetes mellitus, multiple sclerosis, Reynaud's syndrome, autoimmune thyroiditis, experimental autoimmune encephalomyelitis, Sjorgen's syndrome,
35 juvenile onset diabetes, and immune responses associated with delayed hypersensitivity mediated by cytokines and T-lymphocytes typically found in tuberculosis, sarcoidosis, polymyositis,

granulomatosis and vasculitis; pernicious anemia; chronic obstructive pulmonary disease (COPD); bronchitis; insulinitis; rhinitis; urticaria; glomerulonephritis; diseases involving leukocyte diapedesis; CNS inflammatory disorder; multiple organ ,
5 injury syndrome secondary to septicaemia or trauma; autoimmune hemolytic anemia; myethemia gravis; antigen-antibody complex mediated diseases; nephrotic syndrome; malignancies (e.g., B-cell malignancies such as chronic lymphocytic leukemia or hairy cell leukemia); all types of transplantations, including graft vs. host
10 or host vs. graft disease; HIV and rhinovirus infection; pulmonary fibrosis; invasion of tumor cells into secondary organs etc.

A "hypercoagulable state" is one in which due to an inherited or acquired disorder there is an increased propensity for thrombosis. This state is manifested clinically by either an
15 increase in number of thrombotic events or episodes, thrombosis at an early age, a familial tendency toward thrombosis, and thrombosis at unusual sites. Patients that are susceptible to developing a hypercoagulable state include those having the following history: (1) thrombosis at a young age (age under 50
20 years); (2) family history of thrombosis; (3) recurrent thrombosis; (4) thrombosis in an unusual site; and (5) pregnancies complicated by frequent miscarriage. Hypercoagulable states or diseases can be passed onto in family members that inherit particular diseases or abnormalities (e.g., Factor V Leiden
25 Deficiency, Homocystinuria or Hyperhomocysteinemia, Antithrombin III deficiency, Protein C Deficiency, Protein S Deficiency, increased Factor VIII, Fibrinolysis, and Dysfibrinogenemia). Hypercoagulable states can be acquired as a result of other conditions (e.g., pregnancy, estrogen consumption (oral
30 contraceptives, estrogen replacement therapy, tamoxifen), surgery, trauma, infection, bites of poisonous snakes, acute liver disease, sepsis, malignancy (cancer in idiopathic hypercoagulability), myeloproliferative disorder, hyperlipidemia, homocystinuria, systemic lupus erythematosus, burns, renal disease, eclampsia,
35 heat stroke, antiphospholipid antibodies, nephrotic syndrome, neoplasms). Manipulation of body fluids can also result in an undesirable thrombus, particularly in blood transfusions or fluid

sampling, as well as procedures involving extracorporeal circulation (e.g., cardiopulmonary bypass surgery) and dialysis.

"IgE mediated disorders" include atopic disorders, which are characterized by an inherited propensity to respond immunologically to many common naturally occurring inhaled and ingested antigens and the continual production of IgE antibodies. Specific atopic disorders includes allergic asthma, allergic rhinitis, atopic dermatitis and allergic gastroenteropathy. Atopic patients often have multiple allergies, meaning that they have IgE antibodies to, and symptoms from, many environmental allergens, including pollens, fungi (e.g., molds), animal and insect debris and certain foods. Disorders associated with elevated IgE levels are not limited to those with an inherited (atopic) etiology. Other disorders associated with elevated IgE levels, that appear to be IgE-mediated and are treatable with the formulations of this present invention include hypersensitivity (e.g., anaphylactic hypersensitivity), eczema, urticaria, allergic bronchopulmonary aspergillosis, parasitic diseases, hyper-IgE syndrome, ataxia-telangiectasia, Wiskott-Aldrich syndrome, thymic aplasia, IgE myeloma and graft-versus-host reaction.

"Mammal" for purposes of treatment refers to any animal classified as a mammal, including humans, domestic and farm animals, nonhuman primates, and zoo, sports, or pet animals, such as dogs, horses, cats, cows, etc.

The terms "cancer" and "cancerous" refer to or describe the physiological condition in mammals that is typically characterized by unregulated cell growth. Examples of cancer include but are not limited to, carcinoma, lymphoma, blastoma, sarcoma, and leukemia. More particular examples of such cancers include squamous cell cancer, lung cancer (including small-cell lung cancer, non-small cell lung cancer, adenocarcinoma of the lung, and squamous carcinoma of the lung), cancer of the peritoneum, hepatocellular cancer, gastric or stomach cancer (including gastrointestinal cancer), pancreatic cancer, glioblastoma, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, colorectal cancer, endometrial or uterine carcinoma, salivary gland carcinoma, kidney or renal cancer, liver cancer,

prostate cancer, vulval cancer, thyroid cancer, hepatic carcinoma and various types of head and neck cancer, as well as B-cell lymphoma (including low grade/follicular non-Hodgkin's lymphoma (NHL); small lymphocytic (SL) NHL; intermediate grade/follicular NHL; intermediate grade diffuse NHL; high grade immunoblastic NHL; high grade lymphoblastic NHL; high grade small non-cleaved cell NHL; bulky disease NHL; mantle cell lymphoma; AIDS-related lymphoma; and Waldenstrom's Macroglobulinemia); chronic lymphocytic leukemia (CLL); acute lymphoblastic leukemia (ALL); Hairy cell leukemia; chronic myeloblastic leukemia; and post-transplant lymphoproliferative disorder (PTLD).

The term "cytotoxic agent" as used herein refers to a substance that inhibits or prevents the function of cells and/or causes destruction of cells. The term is intended to include radioactive isotopes (e.g. At211, I131, I125, Y90, Re 186, Re188, Sm153, Bi212, P32 and radioactive isotopes of Lu), chemotherapeutic agents, and toxins such as small molecule toxins or enzymatically active toxins of bacterial, fungal, plant or animal origin, including fragments and/or variants thereof.

A "chemotherapeutic agent" is a chemical compound useful in the treatment of cancer. Examples of chemotherapeutic agents include alkylating agents such as thiotepa and CYTOXAN® cyclophosphamide; alkyl sulfonates such as busulfan, improsulfan and piposulfan; aziridines such as benzodopa, carboquone, meturedopa, and uredopa; ethylenimines and methylamelamines including altretamine, triethylenemelamine, triethylenephosphoramide, triethylenethiophosphoramide and trimethylolomelamine; acetogenins (especially bullatacin and bullatacinone); a camptothecin (including the synthetic analogue topotecan); bryostatin; callystatin; CC-1065 (including its adozelesin, carzelesin and bizelesin synthetic analogues); cryptophycins (particularly cryptophycin 1 and cryptophycin 8); dolastatin; duocarmycin (including the synthetic analogues, KW-2189 and CB1-TM1); eleutherobin; pancratistatin; a sarcodictyin; spongistatin; nitrogen mustards such as chlorambucil, chlornaphazine, cholophosphamide, estramustine, ifosfamide, mechlorethamine, mechlorethamine oxide hydrochloride, melphalan,

novembichin, phenesterine, prednimustine, trofosfamide, uracil
mustard; nitrosureas such as carmustine, chlorozotocin,
fotemustine, lomustine, nimustine, and ranimustine; antibiotics
such as the enediyne antibiotics (e. g., calicheamicin, especially
5 calicheamicin gammaII and calicheamicin omegaII (see, e.g., Agnew,
Chem Intl. Ed. Engl., 33: 183-186 (1994)); dynemicin, including
dynemicin A; bisphosphonates, such as clodronate; an esperamicin;
as well as neocarzinostatin chromophore and related chromoprotein
enediyne antiobiotic chromophores), aclacinomysins, actinomycin,
10 authramycin, azaserine, bleomycins, cactinomycin, carabycin,
carminomycin, carzinophilin, chromomycinis, dactinomycin,
daunorubicin, detorubicin, 6-diazo-5-oxo-L-norleucine, ADRIAMYCIN®
doxorubicin (including morpholino-doxorubicin, cyanomorpholino-
doxorubicin, 2-pyrrolino-doxorubicin and deoxydoxorubicin),
15 epirubicin, esorubicin, idarubicin, marcellomycin, mitomycins such
as mitomycin C, mycophenolic acid, nogalamycin, olivomycins,
peplomycin, potfiromycin, puromycin, quelamycin, rodorubicin,
streptonigrin, streptozocin, tubercidin, ubenimex, zinostatin,
zorubicin; anti-metabolites such as methotrexate and 5-
20 fluorouracil (5-FU); folic acid analogues such as denopterin,
methotrexate, pteropterin, trimetrexate; purine analogs such as
fludarabine, 6-mercaptopurine, thiamiprine, thioguanine;
pyrimidine analogs such as ancitabine, azacitidine, 6-azauridine,
carmofur, cytarabine, dideoxyuridine, doxifluridine, enocitabine,
25 floxuridine; androgens such as calusterone, dromostanolone
propionate, epitiostanol, mepitiothane, testolactone; anti-
adrenals such as aminoglutethimide, mitotane, trilostane; folic
acid replenisher such as frolinic acid; aceglatone;
aldophosphamide glycoside; aminolevulinic acid; eniluracil;
30 amsacrine; bestrabucil; bisantrene; edatraxate; defofamine;
demecolcine; diaziquone; elfornithine; elliptinium acetate; an
epothilone; etoglucid; gallium nitrate; hydroxyurea; lentinan;
lonidainine; maytansinoids such as maytansine and ansamitocins;
mitoguazone; mitoxantrone; mopidanmol; nitraerine; pentostatin;
35 phenamet; pirarubicin; lsoxantrone; podophyllinic acid; 2-
ethylhydrazide; procarbazine; PSK® polysaccharide complex (JHS
Natural Products, Eugene, OR); razoxane; rhizoxin; sizofiran;

spirogermanium; tenuazonic acid; triaziquone; 2,2',2"-trichlorotriethylamine; trichothecenes (especially T-2 toxin, verracurin A, roridin A and anguidine); urethan; vindesine; dacarbazine; mannomustine; mitobronitol; mitolactol; pipobroman; gacytosine; arabinoside ("Ara-C"); cyclophosphamide; thiotepa; taxoids, e.g., TAXOL® paclitaxel (Bristol-Myers Squibb Oncology, Princeton, N.J.), ABRAXANE™ Cremophor-free, albumin-engineered nanoparticle formulation of paclitaxel (American Pharmaceutical Partners, Schaumburg, Illinois), and TAXOTERE® docetaxel (Rhône-Poulenc Rorer, Antony, France); chloranbucil; GEMZAR® gemcitabine; 6-thioguanine; mercaptopurine; methotrexate; platinum analogs such as cisplatin and carboplatin; vinblastine; platinum; etoposide (VP-16); ifosfamide; mitoxantrone; vincristine; NAVELBINE® vinorelbine; novantrone; teniposide; edatrexate; daunomycin; aminopterin; xeloda; ibandronate; CPT-11; topoisomerase inhibitor RFS 2000; difluoromethylornithine (DMFO); retinoids such as retinoic acid; capecitabine; and pharmaceutically acceptable salts, acids or derivatives of any of the above. Also included in this definition are anti-hormonal agents that act to regulate or inhibit hormone action on tumors such as anti-estrogens and selective estrogen receptor modulators (SERMs), including, for example, tamoxifen (including NOLVADEX® tamoxifen), raloxifene, droloxifene, 4-hydroxytamoxifen, trioxifene, keoxifene, LY117018, onapristone, and FARESTON, toremifene; aromatase inhibitors that inhibit the enzyme aromatase, which regulates estrogen production in the adrenal glands, such as, for example, 4(5)-imidazoles, aminoglutethimide, MEGASE® megestrol acetate, AROMASIN® exemestane, formestane, fadrozole, RIVISOR® vorozole, FEMARA® letrozole, and ARIMIDEX® anastrozole; and anti-androgens such as flutamide, nilutamide, bicalutamide, leuprolide, and goserelin; as well as troxacitabine (a 1,3-dioxolane nucleoside cytosine analog); antisense oligonucleotides, particularly those which inhibit expression of genes in signaling pathways implicated in aberrant cell proliferation, such as, for example, PKC-alpha, Ralf and H-Ras; ribozymes such as a VEGF expression inhibitor (e.g., ANGIOZYME® ribozyme) and a HER2 expression inhibitor; vaccines such as gene

therapy vaccines, for example, ALLOVECTIN® vaccine, LEUVECTIN® vaccine, and VAXID® vaccine; PROLEUKIN® rIL-2; LURTOTECAN® topoisomerase 1 inhibitor; ABARELIX® rmRH; and pharmaceutically acceptable salts, acids or derivatives of any of the above.

5 An "isolated" nucleic acid molecule is a nucleic acid molecule that is identified and separated from at least one contaminant nucleic acid molecule with which it is ordinarily associated in the natural source of the antibody nucleic acid.

10 An isolated nucleic acid molecule is other than in the form or setting in which it is found in nature. Isolated nucleic acid molecules therefore are distinguished from the nucleic acid molecule as it exists in natural cells. However, an isolated nucleic acid molecule includes a nucleic acid molecule contained in cells that ordinarily express the antibody where, for example,
15 the nucleic acid molecule is in a chromosomal location different from that of natural cells.

20 The expression "control sequences" refers to DNA sequences necessary for the expression of an operably linked coding sequence in a particular host organism. The control sequences that are suitable for prokaryotes, for example, include a promoter, optionally an operator sequence, and a ribosome binding site. Eukaryotic cells are known to utilize promoters, polyadenylation signals, and enhancers.

25 Nucleic acid is "operably linked" when it is placed into a functional relationship with another nucleic acid sequence. For example, DNA for a presequence or secretory leader is operably linked to DNA for a polypeptide if it is expressed as a preprotein that participates in the secretion of the polypeptide; a promoter or enhancer is operably linked to a coding sequence if it affects
30 the transcription of the sequence; or a ribosome binding site is operably linked to a coding sequence if it is positioned so as to facilitate translation. Generally, "operably linked" means that the DNA sequences being linked are contiguous, and, in the case of a secretory leader, contiguous and in reading phase. However,
35 enhancers do not have to be contiguous. Linking is accomplished by ligation at convenient restriction sites. If such sites do not exist, the synthetic oligonucleotide adaptors or linkers are used

in accordance with conventional practice.

As used herein, the expressions "cell," "cell line," and "cell culture" are used interchangeably and all such designations include progeny. Thus, the words "transformants" and "transformed
5 cells" include the primary subject cell and cultures derived therefrom without regard for the number of transfers. It is also understood that all progeny may not be precisely identical in DNA content, due to deliberate or inadvertent mutations. Mutant progeny that have the same function or biological activity as
10 screened for in the originally transformed cell are included. Where distinct designations are intended, it will be clear from the context.

As used herein, "library" refers to a plurality of antibody or antibody fragment sequences (for example, altered antibodies of
15 the invention), or the nucleic acids that encode these sequences, the sequences being different in the combination of variant amino acids that are introduced into these sequences according to the methods of the invention.

"Phage display" is a technique by which variant polypeptides
20 are displayed as fusion proteins to a coat protein on the surface of phage, e.g., filamentous phage, particles. One utility of phage display lies in the fact that large libraries of randomized protein variants can be rapidly and efficiently sorted for those sequences that bind to a target molecule with high affinity.
25 Display of peptide and protein libraries on phage has been used for screening millions of polypeptides for ones with specific binding properties. Polyvalent phage display methods have been used for displaying small random peptides and small proteins through fusions to either gene III or gene VIII of filamentous
30 phage. Wells and Lowman, *Curr. Opin. Struct. Biol.*, 3:355-362 (1992), and references cited therein. In monovalent phage display, a protein or peptide library is fused to a gene III or a portion thereof, and expressed at low levels in the presence of wild type gene III protein so that phage particles display one
35 copy...or none of the fusion proteins. Avidity effects are reduced relative to polyvalent phage so that sorting is on the basis of intrinsic ligand affinity, and phagemid vectors are used, which

simplify DNA manipulations. Lowman and Wells, *Methods: A companion to Methods in Enzymology*, 3:205-0216 (1991).

A "phagemid" is a plasmid vector having a bacterial origin of replication, e.g., ColE1, and a copy of an intergenic region of a bacteriophage. The phagemid may be used on any known bacteriophage, including filamentous bacteriophage and lambdoid bacteriophage. The plasmid will also generally contain a selectable marker for antibiotic resistance. Segments of DNA cloned into these vectors can be propagated as plasmids. When cells harboring these vectors are provided with all genes necessary for the production of phage particles, the mode of replication of the plasmid changes to rolling circle replication to generate copies of one strand of the plasmid DNA and package phage particles. The phagemid may form infectious or non-infectious phage particles. This term includes phagemids which contain a phage coat protein gene or fragment thereof linked to a heterologous polypeptide gene as a gene fusion such that the heterologous polypeptide is displayed on the surface of the phage particle.

The term "phage vector" means a double stranded replicative form of a bacteriophage containing a heterologous gene and capable of replication. The phage vector has a phage origin of replication allowing phage replication and phage particle formation. The phage is preferably a filamentous bacteriophage, such as an M13, f1, fd, Pf3 phage or a derivative thereof, or a lambdoid phage, such as lambda, 21, phi80, phi81, 82, 424, 434, etc., or a derivative thereof.

"Oligonucleotides" are short-length, single- or double-stranded polydeoxynucleotides that are chemically synthesized by known methods (such as phosphotriester, phosphite, or phosphoramidite chemistry, using solid-phase techniques such as described in EP 266,032 published 4 May 1988, or via deoxynucleoside H-phosphonate intermediates as described by Froeshler et al., *Nucl. Acids, Res.*, 14:5399-5407 (1986)). Further methods include the polymerase chain reaction and other autopriming methods and oligonucleotide syntheses on solid supports. All of these methods are described in Engels et al.,

Agnew. Chem. Int. Ed. Engl., 28:716-734 (1989). These methods are used if the entire nucleic acid sequence of the gene is known, or the sequence of the nucleic acid complementary to the coding strand is available. Alternatively, if the target amino acid sequence is known, one may infer potential nucleic acid sequences using known and preferred coding residues for each amino acid residue. The oligonucleotides can be purified on polyacrylamide gels or molecular sizing columns or by precipitation.

II. Modes for Carrying out the Invention

10 A. Making and Selecting Altered Antibodies

(i) Parent or starting antibody

The invention herein relates to a method for making or selecting an altered antibody. The parent antibody or starting antibody, generally a non-human antibody, is prepared using techniques available in the art for generating such antibodies.

The parent antibody is directed against a target antigen of interest. Preferably, the target antigen is a biologically important polypeptide and administration of the antibody to a mammal suffering from a disease or disorder can result in a therapeutic benefit in that mammal. However, antibodies directed against nonpolypeptide antigens (such as tumor-associated glycolipid antigens; see US Patent 5,091,178) are also contemplated.

Where the antigen is a polypeptide, it may be a transmembrane molecule (e.g. receptor) or ligand such as a growth factor. Exemplary antigens include molecules such as renin; a growth hormone, including human growth hormone and bovine growth hormone; growth hormone releasing factor; parathyroid hormone; thyroid stimulating hormone; lipoproteins; alpha-1-antitrypsin; insulin A-chain; insulin B-chain; proinsulin; follicle stimulating hormone; calcitonin; luteinizing hormone; glucagon; clotting factors such as factor VIIIIC, factor IX, tissue factor, and von Willebrands factor; anti-clotting factors such as Protein C; atrial natriuretic factor; lung surfactant; a plasminogen activator, such as urokinase or human urine or tissue-type plasminogen activator (t-PA); bombesin; thrombin; hemopoietic growth factor; tumor necrosis factor-alpha and -beta; enkephalinase; RANTES (regulated

on activation normally T-cell expressed and secreted); human macrophage inflammatory protein (MIP-1-alpha); a serum albumin such as human serum albumin; Muellierian-inhibiting substance; relaxin A-chain; relaxin B-chain; prorelaxin; mouse gonadotropin-associated peptide; a microbial protein, such as beta-lactamase; DNase; IgE; a cytotoxic T-lymphocyte associated antigen (CTLA), such as CTLA-4; inhibin; activin; vascular endothelial growth factor (VEGF); receptors for hormones or growth factors; protein A or D; rheumatoid factors; a neurotrophic factor such as bone-derived neurotrophic factor (BDNF), neurotrophin-3, -4, -5, or -6 (NT-3, NT-4, NT-5, or NT-6), or a nerve growth factor; platelet-derived growth factor (PDGF); fibroblast growth factor such as aFGF and bFGF; epidermal growth factor (EGF); transforming growth factor (TGF) such as TGF-alpha and TGF-beta; insulin-like growth factor-I and -II (IGF-I and IGF-II); des(1-3)-IGF-I (brain IGF-I), insulin-like growth factor binding proteins; CD proteins such as CD3, CD4, CD8, CD19 and CD20; erythropoietin; osteoinductive factors; immunotoxins; a bone morphogenetic protein (BMP); an interferon such as interferon-alpha, -beta, and -gamma; colony stimulating factors (CSFs), e.g., M-CSF, GM-CSF, and G-CSF; interleukins (ILs), e.g., IL-1 to IL-10; superoxide dismutase; T-cell receptors; surface membrane proteins; decay accelerating factor; viral antigen such as, for example, a portion of the AIDS envelope; transport proteins; homing receptors; addressins; regulatory proteins; integrins such as CD11a, CD11b, CD11c, CD18, an ICAM, VLA-4 and VCAM; a tumor associated antigen such as HER2, HER3 or HER4 receptor; and fragments of any of the above-listed polypeptides.

Preferred molecular targets for antibodies encompassed by the present invention include CD proteins such as CD3, CD4, CD8, CD19, CD20, CD22, CD40 and CD34; members of the ErbB receptor family such as the EGF receptor, HER2, HER3 or HER4 receptor; cell adhesion molecules such as LFA-1, Mac1, p150,95, VLA-4, ICAM-1, VCAM and $\alpha v/\beta 3$ integrin including either alpha or beta subunits thereof (e.g. anti-CD11a, anti-CD18 or anti-CD11b antibodies); growth factors such as VEGF; IgE; blood group antigens; flk2/flt3 receptor; obesity (OB) receptor; *mpl* receptor; CTLA-4; protein C;

c-met; tissue factor; $\beta 7$ etc.

The antigen used to generate an antibody may be isolated from a natural source thereof, or may be produced recombinantly or made using other synthetic methods. Alternatively, cells comprising
5 native or recombinant antigen can be used as immunogens for making antibodies.

The parent antibody may have pre-existing strong binding affinity for the target antigen. For example, the parent antibody may bind the antigen of interest with a binding affinity (K_d)
10 value of no more than about 5×10^{-7} M, more preferably no more than about 5×10^{-8} M and optionally no more than about 5×10^{-9} M. Generally, the antibody will bind antigen with an affinity in the nanomolar or better range.

Antibody "binding affinity" may be determined by equilibrium
15 methods (e.g. enzyme-linked immunoabsorbent assay (ELISA) or radioimmunoassay (RIA)), or kinetics (e.g. BIACORE™ analysis), for example.

Also, the antibody may be subjected to other "biological activity assays", e.g., in order to evaluate its "potency" or
20 pharmacological activity and potential efficacy as a therapeutic agent. Such assays are known in the art and depend on the target antigen and intended use for the antibody. Examples include the keratinocyte monolayer adhesion assay and the mixed lymphocyte response (MLR) assay for CD11a (see WO98/23761); tumor cell growth
25 inhibition assays (as described in WO 89/06692, for example); antibody-dependent cellular cytotoxicity (ADCC) and complement-mediated cytotoxicity (CDC) assays (US Patent 5,500,362); agonistic activity or hematopoiesis assays (see WO 95/27062); tritiated thymidine incorporation assay; and alamar blue assay to
30 measure metabolic activity of cells in response to a molecule such as VEGF.

In a first step, the non-human antibody, usually, a rodent, murine or non-human primate antibody may be made, but an existing non-human antibody, or sequence information for an existing non-
35 human antibody can also be used. Generally, hybridoma technology is used to generate the non-human antibody, exemplary techniques

for generating such antibodies being provided herein. The amino acid sequences of the variable regions of the non-human antibody, or at least the hypervariable regions thereof, can be determined using techniques well known to the skilled artisan.

5 (ii) *Human framework selection*

The acceptor human frameworks are selected. While the acceptor human frameworks may be from, or derived from, a human immunoglobulin (the VL and/or VH regions thereof), preferably the acceptor human frameworks are from, or derived from, a human
10 consensus framework sequence as such frameworks have been demonstrated to have minimal, or no, immunogenicity in human patients.

Where the acceptor is derived from a human immunoglobulin, one may optionally select a human framework sequence that is
15 selected based on its homology to the non-human framework sequence by aligning the non-human framework sequence with various human framework sequences in a collection of human framework sequences, and selected the most homologous framework sequence as the acceptor.

20 The most preferred human consensus frameworks herein are from, or derived from, VH subgroup III and/or VL kappa subgroup I consensus framework sequences.

Thus, the VH acceptor human framework may comprise one, two, three or all of the following framework sequences:

- 25 FR1 comprising EVQLVESGGGLVQPGGSLRLSCAAS (SEQ ID NO:1),
FR2 comprising WVRQAPGKGLEWV (SEQ ID NO:2),
FR3 comprising FR3 comprises RFTISX1DX2SKNTX3YLMNSLRAEDTAVYYC
(SEQ ID NO:9), wherein X1 is A or R, X2 is T or N, and X3 is A or L,
30 FR4 comprising WGQGTLVTVSS (SEQ ID NO:4).
Preferred VH consensus frameworks include:
human VH subgroup I consensus framework minus Kabat CDRs (SEQ ID NO:23);
human VH subgroup I consensus framework minus extended
35 hypervariable regions (SEQ ID NOs:24-26);
human VH subgroup II consensus framework minus Kabat CDRs (SEQ ID NO:27);

- human VH subgroup II consensus framework minus extended
hypervariable regions (SEQ ID NOs:28-30);
human VH subgroup III consensus framework minus Kabat CDRs (SEQ ID
NO:31);
- 5 human VH subgroup III consensus framework minus extended
hypervariable regions (SEQ ID NO:32-34);
human VH acceptor framework minus Kabat CDRs (SEQ ID NO:35);
human VH acceptor framework minus extended hypervariable regions
(SEQ ID NOs:36-37);
- 10 human VH acceptor 2 framework minus Kabat CDRs (SEQ ID NO:38); or
human VH acceptor 2 framework minus extended hypervariable regions
(SEQ ID NOs:39-41).

Preferably, the VH acceptor human framework comprises one,
two, three or all of the following framework sequences:

- 15 FR1 comprising EVQLVESGGGLVQPGGSLRLSCAAS (SEQ ID NO:1),
FR2 comprising WVRQAPGKGLEWV (SEQ ID NO:2),
FR3 comprising RFTISADTSKNTAYLQMNSLRAEDTAVYYC (SEQ ID NO:10),
RFTISADTSKNTAYLQMNSLRAEDTAVYYCA (SEQ ID NO:11),
RFTISADTSKNTAYLQMNSLRAEDTAVYYCAR (SEQ ID NO:12),
20 RFTISADTSKNTAYLQMNSLRAEDTAVYYCS (SEQ ID NO:13), or
RFTISADTSKNTAYLQMNSLRAEDTAVYYCSR (SEQ ID NO:14)
FR4 comprising WGQGTLVTVSS (SEQ ID NO:4).

The VL acceptor human framework may comprise one, two, three
or all of the following framework sequences:

- 25 FR1 comprising DIQMTQSPSSLSASVGDRVTITC (SEQ ID NO:5),
FR2 comprising WYQQKPGKAPKLLIY (SEQ ID NO:6),
FR3 comprising GVPSRFSGSGSGTDFTLTISLQPEDFATYYC (SEQ ID NO:7),
FR4 comprising FGQGTKVEIK (SEQ ID NO:8).

Preferred VL consensus frameworks include:

- 30 human VL kappa subgroup I consensus framework (SEQ ID NO:42);
human VL kappa subgroup II consensus framework (SEQ ID NO:43);
human VL kappa subgroup III consensus framework (SEQ ID NO:44); or
human VL kappa subgroup IV consensus framework (SEQ ID NO:45)

- While the acceptor may be identical in sequence to the human
35 framework sequence selected, whether that be from a human
immunoglobulin or a human consensus framework, the present
application contemplates that the acceptor sequence may comprise

pre-existing amino acid substitutions relative to the human immunoglobulin sequence or human consensus framework sequence. These pre-existing substitutions are preferably minimal; usually four, three, two or one amino acid differences only relative to the human immunoglobulin sequence or consensus framework sequence.

(iii) *Incorporation of hypervariable region residues into human frameworks*

Hypervariable region residues of the non-human antibody are incorporated into the VL and/or VH acceptor human frameworks. For example, one may incorporate residues corresponding to the Kabat CDR residues, the Chothia hypervariable loop residues, the Abm residues, and/or contact residues. Optionally, the extended hypervariable region residues as follows are incorporated: 24-34 (L1), 50-56 (L2) and 89-97 (L3), 26-35 (H1), 50-65 or 49-65 (H2) and 93-102, 94-102, or 95-102 (H3).

While "incorporation" of hypervariable region residues is discussed herein, it will be appreciated that this can be achieved various ways, for example, nucleic acid encoding the desired amino acid sequence can be generated by mutating nucleic acid encoding the mouse variable domain sequence so that the framework residues thereof are changed to acceptor human framework residues, or by mutating nucleic acid encoding the human variable domain sequence so that the hypervariable domain residues are changed to non-human residues, or by synthesizing nucleic acid encoding the desired sequence, etc.

In the examples herein, hypervariable region-grafted variants were generated by Kunkel mutagenesis of nucleic acid encoding the human acceptor sequences, using a separate oligonucleotide for each hypervariable region. Kunkel *et al.*, *Methods Enzymol.* 154:367-382 (1987). Correct clones were assessed by DNA sequencing.

Previous efforts to transfer the antigen binding information of non-human monoclonal antibodies onto a human acceptor have relied on the introduction of changes within the framework to correct and re-establish proper hypervariable region-antigen interactions. Rather than remodeling the hypervariable region-framework interface by altering framework residues, the present

invention concerns selection of modified hypervariable regions that correct framework deficiencies while still maintaining antigen interactions.

(iv) *Phage display*

5 According to the preferred method, the hypervariable region sequences are selected using phage display technology, as this provides a convenient and fast method for generating and screening many different altered antibodies. However, other methods for making and screening altered antibodies are available to the
10 skilled person.

Phage display technology has provided a powerful tool for generating and selecting novel proteins which bind to a ligand, such as an antigen. Using the techniques of phage display allows the generation of large libraries of protein variants which can be
15 rapidly sorted for those sequences that bind to a target molecule with high affinity. Nucleic acids encoding variant polypeptides are generally fused to a nucleic acid sequence encoding a viral coat protein, such as the gene III protein or the gene VIII protein. Monovalent phage display systems where the nucleic acid
20 sequence encoding the protein or polypeptide is fused to a nucleic acid sequence encoding a portion of the gene III protein have been developed. (Bass, S., *Proteins*, 8:309 (1990); Lowman and Wells, *Methods: A Companion to Methods in Enzymology*, 3:205 (1991)). In a monovalent phage display system, the gene fusion is expressed at
25 low levels and wild type gene III proteins are also expressed so that infectivity of the particles is retained. Methods of generating peptide libraries and screening those libraries have been disclosed in many patents (e.g. U.S. Patent No. 5,723,286, U.S. Patent No. 5,432, 018, U.S. Patent No. 5,580,717, U.S. Patent
30 No. 5,427,908 and U.S. Patent No. 5,498,530).

Libraries of antibodies or antigen binding polypeptides have been prepared in a number of ways including by altering a single gene by inserting random DNA sequences or by cloning a family of related genes. Methods for displaying antibodies or antigen
35 binding fragments using phage display have been described in U.S. Patent Nos. 5,750,373, 5,733,743, 5,837,242, 5,969,108, 6,172,197, 5,580,717, and 5,658,727. The library is then screened for

expression of antibodies or antigen binding proteins with the desired characteristics.

Methods of substituting an amino acid of choice into a template nucleic acid are well established in the art, some of which are described herein. For example, hypervariable region residues can be substituted using the Kunkel method. See, for e.g., Kunkel et al., *Methods Enzymol.* 154:367-382 (1987).

The sequence of oligonucleotides includes one or more of the designed codon sets for the hypervariable region residues to be altered. A codon set is a set of different nucleotide triplet sequences used to encode desired variant amino acids. Codon sets can be represented using symbols to designate particular nucleotides or equimolar mixtures of nucleotides as shown in below according to the IUB code.

15	<u>IUB CODES</u>
	G Guanine
	A Adenine
	T Thymine
	C Cytosine
20	R (A or G)
	Y (C or T)
	M (A or C)
	K (G or T)
	S (C or G)
25	W (A or T)
	H (A or C or T)
	B (C or G or T)
	V (A or C or G)
	D (A or G or T) H
30	N (A or C or G or T)

For example, in the codon set DVK, D can be nucleotides A or G or T; V can be A or G or C; and K can be G or T. This codon set can present 18 different codons and can encode amino acids Ala, Trp, Tyr, Lys, Thr, Asn, Lys, Ser, Arg, Asp, Glu, Gly, and Cys.

Oligonucleotide or primer sets can be synthesized using standard methods. A set of oligonucleotides can be synthesized,

for example, by solid phase synthesis, containing sequences that represent all possible combinations of nucleotide triplets provided by the codon set and that will encode the desired group of amino acids. Synthesis of oligonucleotides with selected
5 nucleotide "degeneracy" at certain positions is well known in that art. Such sets of nucleotides having certain codon sets can be synthesized using commercial nucleic acid synthesizers (available from, for example, Applied Biosystems, Foster City, CA), or can be obtained commercially (for example, from Life Technologies,
10 Rockville, MD). Therefore, a set of oligonucleotides synthesized having a particular codon set will typically include a plurality of oligonucleotides with different sequences, the differences established by the codon set within the overall sequence. Oligonucleotides, as used according to the invention, have
15 sequences that allow for hybridization to a variable domain nucleic acid template and also can include restriction enzyme sites for cloning purposes.

In one method, nucleic acid sequences encoding variant amino acids can be created by oligonucleotide-mediated mutagenesis.
20 This technique is well known in the art as described by Zoller *et al. Nucleic Acids Res.* 10:6487-6504(1987). Briefly, nucleic acid sequences encoding variant amino acids are created by hybridizing an oligonucleotide set encoding the desired codon sets to a DNA template, where the template is the single-stranded form of the
25 plasmid containing a variable region nucleic acid template sequence. After hybridization, DNA polymerase is used to synthesize an entire second complementary strand of the template that will thus incorporate the oligonucleotide primer, and will contain the codon sets as provided by the oligonucleotide set.

30 Generally, oligonucleotides of at least 25 nucleotides in length are used. An optimal oligonucleotide will have 12 to 15 nucleotides that are completely complementary to the template on either side of the nucleotide(s) coding for the mutation(s). This ensures that the oligonucleotide will hybridize properly to the
35 single-stranded DNA template molecule. The oligonucleotides are readily synthesized using techniques known in the art such as that described by Crea *et al.*, *Proc. Nat'l. Acad. Sci. USA*, 75:5765

(1978).

The DNA template is generated by those vectors that are either derived from bacteriophage M13 vectors (the commercially available M13mp18 and M13mp19 vectors are suitable), or those
5 vectors that contain a single-stranded phage origin of replication as described by Viera et al., *Meth. Enzymol.*, 153:3 (1987). Thus, the DNA that is to be mutated can be inserted into one of these vectors in order to generate single-stranded template. Production of the single-stranded template is described in sections 4.21-4.41
10 of Sambrook et al., above.

To alter the native DNA sequence, the oligonucleotide is hybridized to the single stranded template under suitable hybridization conditions. A DNA polymerizing enzyme, usually T7 DNA polymerase or the Klenow fragment of DNA polymerase I, is then
15 added to synthesize the complementary strand of the template using the oligonucleotide as a primer for synthesis. A heteroduplex molecule is thus formed such that one strand of DNA encodes the mutated form of gene 1, and the other strand (the original template) encodes the native, unaltered sequence of gene 1. This
20 heteroduplex molecule is then transformed into a suitable host cell, usually a prokaryote such as *E. coli* JM101. After growing the cells, they are plated onto agarose plates and screened using the oligonucleotide primer radiolabelled with a 32-Phosphate to identify the bacterial colonies that contain the mutated DNA.

25 The method described immediately above may be modified such that a homoduplex molecule is created wherein both strands of the plasmid contain the mutation(s). The modifications are as follows: The single stranded oligonucleotide is annealed to the single-stranded template as described above. A mixture of three
30 deoxyribonucleotides, deoxyriboadenosine (dATP), deoxyriboguanosine (dGTP), and deoxyribothymidine (dTTP), is combined with a modified thiodeoxyribocytosine called dCTP-(aS) (which can be obtained from Amersham). This mixture is added to the template-oligonucleotide complex. Upon addition of DNA
35 polymerase to this mixture, a strand of DNA identical to the template except for the mutated bases is generated. In addition, this new strand of DNA will contain dCTP-(aS) instead of dCTP,

which serves to protect it from restriction endonuclease digestion. After the template strand of the double-stranded heteroduplex is nicked with an appropriate restriction enzyme, the template strand can be digested with ExoIII nuclease or another appropriate nuclease past the region that contains the site(s) to be mutagenized. The reaction is then stopped to leave a molecule that is only partially single-stranded. A complete double-stranded DNA homoduplex is then formed using DNA polymerase in the presence of all four deoxyribonucleotide triphosphates, ATP, and DNA ligase. This homoduplex molecule can then be transformed into a suitable host cell.

As indicated previously the sequence of the oligonucleotide set is of sufficient length to hybridize to the template nucleic acid and may also, but does not necessarily, contain restriction sites. The DNA template can be generated by those vectors that are either derived from bacteriophage M13 vectors or vectors that contain a single-stranded phage origin of replication as described by Viera *et al.* *Meth. Enzymol.*, 153:3 (1987). Thus, the DNA that is to be mutated must be inserted into one of these vectors in order to generate single-stranded template. Production of the single-stranded template is described in sections 4.21-4.41 of Sambrook *et al.*, *supra*.

According to another method, a library can be generated by providing upstream and downstream oligonucleotide sets, each set having a plurality of oligonucleotides with different sequences, the different sequences established by the codon sets provided within the sequence of the oligonucleotides. The upstream and downstream oligonucleotide sets, along with a variable domain template nucleic acid sequence, can be used in a polymerase chain reaction to generate a "library" of PCR products. The PCR products can be referred to as "nucleic acid cassettes", as they can be fused with other related or unrelated nucleic acid sequences, for example, viral coat proteins and dimerization domains, using established molecular biology techniques.

The sequence of the PCR primers includes one or more of the designed codon sets for the solvent accessible and highly diverse positions in a hypervariable region. As described above, a codon

set is a set of different nucleotide triplet sequences used to encode desired variant amino acids.

(v) *Mutagenesis Method*

According to the present invention, preferably large phage
5 display libraries are used. Unfortunately as the number of
oligonucleotides in a mutagenesis reaction increases the frequency
of clones containing all mutagenic oligonucleotides decreases. To
compensate for this, one could increase the oligonucleotide
concentration to ensure that all sites are fully occupied during
10 the annealing process; however, as the concentration of
oligonucleotides in the polymerase reaction increases, the
potential for side reactions also increases resulting in a
decreased yield of mutagenized clones and an overall reduced
library size. To overcome this problem, a "clean-up step" was
15 developed herein, to remove excess un-annealed oligonucleotides
prior to the polymerase reaction. Aside from use with respect to
selecting altered antibodies, namely CDR-repaired antibodies as
described herein, it is believed that this methodology is useful
in other situations where nucleic acid is mutated, particularly
20 where a large number of oligonucleotides are employed during
mutagenesis.

Accordingly, a 3-step method for mutating a nucleic acid
sequence comprising:

- (a) annealing from about two to about 20 oligonucleotides to a
25 single stranded nucleic acid template, wherein the
oligonucleotide:template ratio for each oligonucleotide is greater
than 1;
- (b) removing excess unannealed oligonucleotides; and
- (c) filling in a nucleic acid strand which is complementary to the
30 template.

The template in step (a) can be the coding (or complementary
strand thereof) for an antibody or altered antibody (e.g. a CDR
repaired antibody variant herein or an altered antibody with
hypervariable regions from a non-human antibody incorporated into
35 a acceptor human framework). In this embodiment, the mutagenesis
may be used to substitute one or more hypervariable region
residues of the antibody or altered antibody. Preferably the

antibody or altered antibody is in the form of an antibody fragment, such as a scFv or Fab fragment, which may be displayed on phage.

Step (b) preferably comprises exposing a mixture of the
5 template and annealed or unannealed oligonucleotides to a reagent that enables the template to bind to a silica matrix, but not oligonucleotides shorter than 100 base pairs in length. Following exposure to the reagent, the composition is run through a solid phase (e.g. silica column), the unannealed oligonucleotides are
10 washed from the solid phase. Following this step, the template may be recovered from the solid phase. This step separates unannealed oligonucleotides away from the template with annealed oligonucleotides. Preferably the reagent comprises guanidine hydrochloride, e.g., PB (QIAQUICK). In step (a), the
15 oligo:template ratio for each oligo is greater than 1, such that the oligonucleotides saturate corresponding sites on the template. Generally, at least a 2-3 fold excess of each oligo, e.g. a 10 fold excess, is used.

Following the clean up step, the complementary second strand
20 of nucleic acid is filled in, using e.g. polymerase, and ligase to complete synthesis of the second strand.

(vi) *Soft randomization*

In the preferred embodiment of the present invention, a technique called "soft randomization" of the hypervariable regions
25 is used. This maintains a bias towards the murine hypervariable region sequence, while introducing a 10-50 percent mutation at each selected position. This technique increases the capacity of the library screening employed and avoids a change in the antigen epitope recognized by the antibody. According to this soft
30 randomization technique, sequence diversity is introduced into each hypervariable region using a strategy that maintains a bias towards the murine hypervariable region sequence. This was accomplished using a poisoned oligonucleotide synthesis strategy first described by Gallop et al., *J. Med. Chem.* 37:1233-1251
35 (1994). However, other methods for maintaining a bias towards the non-human hypervariable region residue are available, such as error prone PCR, DNA shuffling, etc.

According to the preferred method herein, for a given position within a hypervariable region to be mutated, the codon encoding the wild-type amino acid is poisoned with a mixture (e.g. a 70-10-10-10 mixture) of nucleotides resulting in an approximately 10-50 percent mutation rate at each selected hypervariable region position. To achieve this, the codon encoding the wild-type hypervariable region amino acid to be mutated is synthesized with a low level of contaminating mixture of the other three nucleotides, such as a 70-10-10-10 mixture of nucleotides. Thus, by way of example, for soft randomization of met (ATG), the first position synthesized is a mixture of 70% A, and 10% each of G, T and C; the second position is a mixture of 70% T, and 10% each of A, G, and C; and the third position is a mixture of 70% G, and 10% each of A, C and T.

Soft randomized oligonucleotides can be patterned after the murine hypervariable region sequences and encompass the same regions defined by the direct hypervariable region grafts. Optionally, two positions, amino acids at the beginning of H2 and H3 in the VH domain, may be limited in their diversity: the codon RGC may be used for position 49 encoding A, G, S or T and at position 94, the codon ARA may be used encoding R or K.

(vii) Expression vectors and transformed hosts

Nucleic acid cassettes can be cloned into any suitable vector for expression of a portion or the entire light or heavy chain sequence containing the targeted amino acid substitutions generated via the PCR reaction. According to methods detailed in the invention, the nucleic acid cassette is cloned into a vector allowing production of a portion or the entire light or heavy chain sequence fused to all or a portion of a viral coat protein (i.e., creating a fusion protein) and displayed on the surface of a particle or cell. While several types of vectors are available and may be used to practice this invention, phagemid vectors are the preferred vectors for use herein, as they may be constructed with relative ease, and can be readily amplified. Phagemid vectors generally contain a variety of components including promoters, signal sequences, phenotypic selection genes, origin of replication sites, and other necessary components as are known to

those of ordinary skill in the art. In another embodiment, wherein a particular variant amino acid combination is to be expressed, the nucleic acid cassette contains a sequence that is able to encode all or a portion of the heavy or light chain variable domain, and is able to encode the variant amino acid combinations. For production of antibodies containing these variant amino acids or combinations of variant amino acids, as in a library, the nucleic acid cassettes can be inserted into an expression vector containing additional antibody sequence, for example all or portions of the variable or constant domains of the light and heavy chain variable regions. These additional antibody sequences can also be fused to other nucleic acids sequences, such as sequences which encode viral coat proteins and therefore allow production of a fusion protein.

The present invention provides a replicable expression vector comprising a nucleic acid sequence encoding a gene fusion, wherein the gene fusion encodes a fusion protein comprising an antibody variable domain, or an antibody variable domain and a constant domain, fused to all or a portion of a viral coat protein. Also included is a library of diverse replicable expression vectors comprising a plurality of gene fusions encoding a plurality of different fusion proteins including a plurality of the antibody variable domains generated with diverse sequences as described above. The vectors can include a variety of components and are preferably constructed to allow for movement of antibody variable domain between different vectors and/or to provide for display of the fusion proteins in different formats.

The preferred phagemid is a monovalent Fab-g3 display vector, which may consist of 2 open reading frames under control of an appropriate promoter, such as the phoA promoter. The first open reading frame may comprise a signal sequence (e.g. the stII signal sequence) fused to the light chain sequence and the second open reading frame may comprise a signal sequence (e.g. the stII signal sequence) fused to the VH and CH1 domains of the heavy chain sequence, optionally followed by the minor phage coat protein P3.

Examples of vectors include phage vectors. The phage vector has a phage origin of replication allowing phage replication and

phage particle formation. The phage is preferably a filamentous bacteriophage, such as an M13, f1, fd, Pf3 phage or a derivative thereof, or a lambdoid phage, such as lambda, 21, phi80, phi81, 82, 424, 434, etc., or a derivative thereof.

5 Examples of viral coat proteins include infectivity protein PIII, major coat protein PVIII, p3, Soc, Hoc, gpD (of bacteriophage lambda), minor bacteriophage coat protein 6 (pVI) (filamentous phage; *J Immunol Methods*. 231(1-2):39-51 (1999)), variants of the M13 bacteriophage major coat protein (P8) (*Protein*
10 *Sci* 9(4):647-54 (2000)). The fusion protein can be displayed on the surface of a phage and suitable phage systems include M13K07 helper phage, M13R408, M13-VCS, and Phi X 174, pJuFo phage system (*J Virol*. 75(15):7107-13.v (2001)), hyperphage (*Nat Biotechnol*. 19(1):75-8 (2001)). The preferred helper phage is M13K07, and the
15 preferred coat protein is the M13 Phage gene III coat protein. The preferred host is *E. coli*, and protease deficient strains of *E. coli*. Vectors, such as the fth1 vector (*Nucleic Acids Res*. 29(10):E50-0 (2001)) can be useful for the expression of the fusion protein.

20 The expression vector also can have a secretory signal sequence fused to the DNA encoding each subunit of the antibody or fragment thereof. This sequence is typically located immediately 5' to the gene encoding the fusion protein, and will thus be transcribed at the amino terminus of the fusion protein. However,
25 in certain cases, the signal sequence has been demonstrated to be located at positions other than 5' to the gene encoding the protein to be secreted. This sequence targets the protein to which it is attached across the inner membrane of the bacterial cell. The DNA encoding the signal sequence may be obtained as a
30 restriction endonuclease fragment from any gene encoding a protein that has a signal sequence. Suitable prokaryotic signal sequences may be obtained from genes encoding, for example, LamB or OmpF (Wong et al., *Gene*, 68:1931 (1983), MalE, PhoA and other genes. A preferred prokaryotic signal sequence for practicing this
35 invention is the *E. coli* heat-stable enterotoxin II (STII) signal sequence as described by Chang et al., *Gene* 55:189 (1987), and malE.

The vector also typically includes a promoter to drive expression of the fusion protein. Promoters most commonly used in prokaryotic vectors include the lac Z promoter system, the alkaline phosphatase pho A promoter, the bacteriophage ϕ_{PL} promoter (a temperature sensitive promoter), the tac promoter (a hybrid trp-lac promoter that is regulated by the lac repressor), the tryptophan promoter, and the bacteriophage T7 promoter. For general descriptions of promoters, see section 17 of Sambrook et al. *supra*. While these are the most commonly used promoters, other suitable microbial promoters may be used as well.

The vector can also include other nucleic acid sequences, for example, sequences encoding gD tags, c-Myc epitopes, poly-histidine tags, fluorescence proteins (e.g., GFP), or beta-galactosidase protein which can be useful for detection or purification of the fusion protein expressed on the surface of the phage or cell. Nucleic acid sequences encoding, for example, a gD tag, also provide for positive or negative selection of cells or virus expressing the fusion protein. In some embodiments, the gD tag is preferably fused to an antibody variable domain which is not fused to the viral coat protein. Nucleic acid sequences encoding, for example, a polyhistidine tag, are useful for identifying fusion proteins including antibody variable domains that bind to a specific antigen using immunohistochemistry. Tags useful for detection of antigen binding can be fused to either an antibody variable domain not fused to a viral coat protein or an antibody variable domain fused to a viral coat protein.

Another useful component of the vectors used to practice this invention is phenotypic selection genes. Typical phenotypic selection genes are those encoding proteins that confer antibiotic resistance upon the host cell. By way of illustration, the ampicillin resistance gene (*amp^r*), and the tetracycline resistance gene (*tetr*) are readily employed for this purpose.

The vector can also include nucleic acid sequences containing unique restriction sites and suppressible stop codons. The unique restriction sites are useful for moving antibody variable domains between different vectors and expression systems. The suppressible stop codons are useful to control the level of expression of the

fusion protein and to facilitate purification of soluble antibody fragments. For example, an amber stop codon can be read as Gln in a *supE* host to enable phage display, while in a non-*supE* host it is read as a stop codon to produce soluble antibody fragments
5 without fusion to phage coat proteins. These synthetic sequences can be fused to one or more antibody variable domains in the vector.

It is preferable to use vector systems that allow the nucleic acid encoding an antibody sequence of interest, for example a CDR-repaired antibody, to be easily removed from the vector system and
10 placed into another vector system. For example, appropriate restriction sites can be engineered in a vector system to facilitate the removal of the nucleic acid sequence encoding an antibody or antibody variable domain having variant amino acids.
15 The restriction sequences are usually chosen to be unique in the vectors to facilitate efficient excision and ligation into new vectors. Antibodies or antibody variable domains can then be expressed from vectors without extraneous fusion sequences, such as viral coat proteins or other sequence tags.

Between nucleic acid encoding antibody variable domain (gene 1) and the viral coat protein (gene 2), DNA encoding a termination codon may be inserted, such termination codons including UAG (amber), UAA (ocher) and UGA (opal). (Davis *et al. Microbiology*, Harper & Row, New York, pp. 237, 245-47 and 374 (1980)). The
20 termination codon expressed in a wild type host cell results in the synthesis of the gene 1 protein product without the gene 2 protein attached. However, growth in a suppressor host cell results in the synthesis of detectable quantities of fused protein. Such suppressor host cells are well known and described,
25 such as *E. coli* suppressor strain (Bullock *et al., BioTechniques* 5:376-379 (1987)). Any acceptable method may be used to place such a termination codon into the mRNA encoding the fusion polypeptide.
30

The suppressible codon may be inserted between the first gene
35 encoding an antibody variable domain, and a second gene encoding at least a portion of a phage coat protein. Alternatively, the suppressible termination codon may be inserted adjacent to the

fusion site by replacing the last amino acid triplet in the antibody variable domain or the first amino acid in the phage coat protein. When the plasmid containing the suppressible codon is grown in a suppressor host cell, it results in the detectable
5 production of a fusion polypeptide containing the polypeptide and the coat protein. When the plasmid is grown in a non-suppressor host cell, the antibody variable domain is synthesized substantially without fusion to the phage coat protein due to termination at the inserted suppressible triplet UAG, UAA, or UGA.
10 In the non-suppressor cell the antibody variable domain is synthesized and secreted from the host cell due to the absence of the fused phage coat protein which otherwise anchored it to the host membrane.

The light and/or heavy antibody variable domains can also be
15 fused to an additional peptide sequence, the additional peptide sequence allowing the interaction of one or more fusion polypeptides on the surface of the viral particle or cell. These peptide sequences are herein referred to as "dimerization sequences", "dimerization peptides" or "dimerization domains".
20 Suitable dimerization domains include those of proteins having amphipathic alpha helices in which hydrophobic residues are regularly spaced and allow the formation of a dimer by interaction of the hydrophobic residues of each protein; such proteins and portions of proteins include, for example, leucine zipper regions.
25 The dimerization regions are preferably located between the antibody variable domain and the viral coat protein.

In some cases the vector encodes a single antibody-phage polypeptide in a single chain form containing, for example, both the heavy and light chain variable regions fused to a coat
30 protein. In these cases the vector is considered to be "monocistronic", expressing one transcript under the control of a certain promoter. This cistronic sequence may be connected at the 5' end to an *E. coli malE* or heat-stable enterotoxin II (STII) signal sequence and at its 3' end to all or a portion of a viral
35 coat.

In other cases, the variable regions of the heavy and light chains can be expressed as separate polypeptides, the vector thus

being "bicistronic", allowing the expression of separate transcripts. In these vectors, a suitable promoter, such as the Ptac or PhoA promoter, can be used to drive expression of a bicistronic message. A first cistron, encoding, for example, a light chain variable domain, is connected at the 5' end to a *E. coli malE* or heat-stable enterotoxin II (STII) signal sequence and at the 3' end to a nucleic acid sequence encoding a gD tag. A second cistron, encoding, for example, a heavy chain variable domain, is connected at its 5' end to a *E. coli malE* or heat-stable enterotoxin II (STII) signal sequence and at the 3' end to all or a portion of a viral coat protein.

Fusion polypeptides with an antibody variable domain can be displayed on the surface of a cell or virus in a variety of formats. These formats include single chain Fv fragment (scFv), F(ab) fragment and multivalent forms of these fragments. The multivalent forms preferably are a dimer of ScFv, Fab, or F(ab)', herein referred to as (ScFv)₂, F(ab)₂ and F(ab)'₂, respectively. The multivalent forms of display are preferred in part because they have more than one antigen binding site which generally results in the identification of lower affinity clones and also allows for more efficient sorting of rare clones during the selection process.

Methods for displaying fusion polypeptides comprising antibody fragments, on the surface of bacteriophage, are well known in the art, for example as described in patent publication number WO 92/01047 and herein. Other patent publications WO 92/20791; WO 93/06213; WO 93/11236 and WO 93/19172, describe related methods and are all herein incorporated by reference. Other publications have shown the identification of antibodies with artificially rearranged V gene repertoires against a variety of antigens displayed on the surface of phage (for example, Hoogenboom & Winter *J. Mol. Biol.* 227 381-388 (1992); and as disclosed in WO 93/06213 and WO 93/11236).

When a vector is constructed for display in a scFv format, it includes nucleic acid sequences encoding an antibody variable light chain domain and an antibody variable heavy chain variable domain. Typically, the nucleic acid sequence encoding an antibody

variable heavy chain domain is fused to a viral coat protein. The nucleic acid sequence encoding the antibody variable light chain is connected to the antibody variable heavy chain domain by a nucleic acid sequence encoding a peptide linker. The peptide
5 linker typically contains about 5 to 15 amino acids. Optionally, other sequences encoding, for example, tags useful for purification or detection can be fused at the 3' end of either the nucleic acid sequence encoding the antibody variable light chain or antibody variable heavy chain domain or both.

10 When a vector is constructed for F(ab) display, it includes nucleic acid sequences encoding antibody variable domains and antibody constant domains. A nucleic acid encoding a variable light chain domain is fused to a nucleic acid sequence encoding a light chain constant domain. A nucleic acid sequence encoding an
15 antibody heavy chain variable domain is fused to a nucleic acid sequence encoding a heavy chain constant CH1 domain. Typically, the nucleic acid sequence encoding the heavy chain variable and constant domains are fused to a nucleic acid sequence encoding all or part of a viral coat protein. The heavy chain variable and
20 constant domains are preferably expressed as a fusion with at least a portion of a viral coat protein and the light chain variable and constant domains are expressed separately from the heavy chain viral coat fusion protein. The heavy and light chains associate with one another, via covalent or non-covalent bond(s).
25 Optionally, other sequences encoding, for example, polypeptide tags useful for purification or detection, can be fused at the 3' end of either the nucleic acid sequence encoding the antibody light chain constant domain or antibody heavy chain constant domain or both.

30 Preferably a bivalent moiety, for example, a F(ab)₂ dimer or F(ab)'₂ dimer, is used for displaying antibody fragments with the variant amino acid substitutions on the surface of a particle. It has been found that F(ab)'₂ dimers have the same affinity as F(ab) dimers in a solution phase antigen binding assay but the off rate
35 for F(ab)'₂ are reduced because of a higher avidity in an assay with immobilized antigen. Therefore the bivalent format (for

example, F(ab)'₂) is a particularly useful format since it can allow the identification of lower affinity clones and also allows more efficient sorting of rare clones during the selection process.

5 Vectors may be introduced into a host cell for amplification and/or expression. Vectors can be introduced into host cells using standard transformation methods including electroporation, calcium phosphate precipitation and the like. If the vector is an infectious particle such as a virus, the vector itself provides
10 for entry into the host cell. Transfection of host cells containing a replicable expression vector which encodes the gene fusion and production of phage particles according to standard procedures provides phage particles in which the fusion protein is displayed on the surface of the phage particle.

15 Replicable expression vectors are introduced into host cells using a variety of methods. In one embodiment, vectors can be introduced into cells using electroporation as described in WO/00106717. Cells are grown in culture in standard culture broth, optionally for about 6-48 hours (or to OD₆₀₀ = 0.6 - 0.8) at
20 about 37°C, and then the broth is centrifuged and the supernatant removed (e.g. decanted). Initial purification may be achieved by resuspending the cell pellet in a buffer solution (e.g. 1.0 mM HEPES pH 7.4) followed by recentrifugation and removal of supernatant. The resulting cell pellet is resuspended in dilute
25 glycerol (e.g. 5-20% v/v) and again recentrifuged to form a cell pellet and the supernatant removed. The final cell concentration is obtained by resuspending the cell pellet in water or dilute glycerol to the desired concentration.

 An exemplary recipient cell is the electroporation competent
30 *E. coli* strain of the present invention, which is *E. coli* strain SS320 (Sidhu et al., *Methods Enzymol.* 328:333-363 (2000)). Strain SS320 was prepared by mating MC1061 cells with XL1-BLUE cells under conditions sufficient to transfer the fertility episome (F' plasmid) or XL1-BLUE into the MC1061 cells. Strain SS320 has been
35 deposited with the American Type Culture Collection (ATCC), 10801 University Boulevard, Manassas, Virginia USA, on June 18, 1998 and

assigned Deposit Accession No. 98795. Any F' episome which enables phage replication in the strain may be used in the invention. Suitable episomes are available from strains deposited with ATCC or are commercially available (CJ236, CSH18, DHF',
5 JM101, JM103, JM105, JM107, JM109, JM110, KS1000, XL1-BLUE, 71-18 and others).

The use of higher DNA concentrations during electroporation (about 10X) increases the transformation efficiency and increases the amount of DNA transformed into the host cells. The use of
10 high cell concentrations also increases the efficiency (about 10X). The larger amount of transferred DNA produces larger libraries having greater diversity and representing a greater number of unique members of a combinatorial library. Transformed cells are generally selected by growth on antibiotic containing
15 medium.

(viii) Screening for altered antibodies that bind antigen

Phage display of proteins, peptides and mutated variants thereof, involves constructing a family of variant replicable vectors containing a transcription regulatory element operably
20 linked to a gene fusion encoding a fusion polypeptide, transforming suitable host cells, culturing the transformed cells to form phage particles which display the fusion polypeptide on the surface of the phage particle, contacting the recombinant phage particles with a target molecule so that at least a portion
25 of the particle bind to the target, and separating the particles which bind from particle that do not bind.

Antibody variable domain fusion proteins expressing the variant amino acids can be expressed on the surface of a phage or a cell and then screened for the ability of members of the group
30 of fusion proteins to bind a target molecule, such as a target protein, which is typically an antigen of interest. Target proteins can also include protein L which binds to antibody or antibody fragments and can be used to enrich for library members that display correctly folded antibody fragments (fusion
35 polypeptides). Target proteins, such as receptors, may be isolated from natural sources or prepared by recombinant methods by procedures known in the art.

Screening for the ability of a fusion polypeptide to bind a target molecule can also be performed in solution phase. For example, a target molecule can be attached with a detectable moiety, such as biotin. Phage that binds to the target molecule in solution can be separated from unbound phage by a molecule that binds to the detectable moiety, such as streptavidin-coated beads where biotin is the detectable moiety. Affinity of binders (fusion polypeptide that binds to target) can be determined based on concentration of the target molecule used, using formulas and based on criteria known in the art.

The purified target protein may be attached to a suitable matrix such as agarose beads, acrylamide beads, glass beads, cellulose, various acrylic copolymers, hydroxyalkyl methacrylate gels, polyacrylic and polymethacrylic copolymers, nylon, neutral and ionic carriers, and the like. Attachment of the target protein to the matrix may be accomplished by methods described in *Methods in Enzymology*, 44 (1976), or by other means known in the art.

After attachment of the target protein to the matrix, the immobilized target is contacted with the library expressing the fusion polypeptides under conditions suitable for binding of at least a portion of the phage particles with the immobilized target. Normally, the conditions, including pH, ionic strength, temperature and the like will mimic physiological conditions. Bound particles ("binders") to the immobilized target are separated from those particles that do not bind to the target by washing. Wash conditions can be adjusted to result in removal of all but the higher affinity binders. Binders may be dissociated from the immobilized target by a variety of methods. These methods include competitive dissociation using the wild-type ligand, altering pH and/or ionic strength, and methods known in the art. Selection of binders typically involves elution from an affinity matrix with a ligand. Elution with increasing concentrations of ligand should elute displayed binding molecules of increasing affinity.

The binders can be isolated and then reamplified or expressed in a host cell and subjected to another round of selection for binding of target molecules. Any number of rounds of selection or

sorting can be utilized. One of the selection or sorting procedures can involve isolating binders that bind to protein L or an antibody to a polypeptide tag such as antibody to the gD protein or polyhistidine tag.

5 In some cases, suitable host cells are infected with the binders and helper phage, and the host cells are cultured under conditions suitable for amplification of the phagemid particles. The phagemid particles are then collected and the selection process is repeated one or more times until binders having the
10 desired affinity for the target molecule are selected. Preferably at least 2 rounds of selection are conducted.

After binders are identified by binding to the target antigen, the nucleic acid can be extracted. Extracted DNA can then be used directly to transform *E. coli* host cells or
15 alternatively, the encoding sequences can be amplified, for example using PCR with suitable primers, and then inserted into a vector for expression.

A preferred strategy to isolate high affinity binders is to bind a population of phage to an affinity matrix which contains a
20 low amount of ligand. Phage displaying high affinity polypeptide is preferentially bound and low affinity polypeptide is washed away. The high affinity polypeptide is then recovered by elution with the ligand or by other procedures which elute the phage from the affinity matrix.

25 Preferably, the process of screening is carried out by automated systems to allow for high-throughput screening of library candidates.

In some embodiments, libraries comprising polypeptides of the invention are subjected to a plurality of sorting rounds, wherein
30 each sorting round comprises contacting the binders obtained from the previous round with a target molecule distinct from the target molecule(s) of the previous round(s). Preferably, but not necessarily, the target molecules are homologous in sequence, for example members of a family of related but distinct polypeptides,
35 such as, but not limited to, cytokines (for example, alpha interferon subtypes).

In the preferred embodiment of the invention the antigen, or

a fragment thereof is coated on microtiter plates and binding thereto is assessed, e.g. by phage ELISA as in the example below.

One or more rounds of selection may be carried out.

Significant enrichment may be observed by the second, third or
5 subsequent round of selection, and random clones may be selected from the first, second, third, fourth and/or subsequent rounds of panning and analyzed by phage ELISA and DNA sequence analysis.

The altered antibodies will have mutation(s) in one or more hypervariable regions thereof. In the examples herein, for the
10 anti-IgE and anti-LFA-1 libraries, mutations were almost exclusively located in H1 and L2, respectively, while mutations in the anti-TF library were limited to one of the three hypervariable regions in the VL domain. Without being bound to any one theory, this indicates that these locations are the regions where
15 solutions to a poor fit of the murine hypervariable regions on the human framework can be found.

The mutations may occur at position 34 and/or 35 of H1. Moreover, the mutated hypervariable region residue(s) may be buried and/or may interact with the framework according to the
20 structure of the humanized antibody. Alternatively, or additionally, the mutated hypervariable region residue(s) may be centrally located near the surface of the VH domain so that they may also potentially affect the structural conformations of one or more other hypervariable regions, e.g. with H2 and/or H3.

25 Following production of the altered antibody, the activity of that molecule relative to the parent antibody may be determined. As noted above, this may involve determining the binding affinity and/or other biological activities of the antibody. In a preferred embodiment of the invention, a panel of antibody
30 variants are prepared and are screened for binding affinity for the antigen and/or potency in one or more biological activity assays. The affinities achieved are preferably similar to, e.g. no less than 100 fold, or no less than 10 fold the affinity of the non-human parent antibody. For example, the antibody variant of
35 interest may bind the antigen of interest with a binding affinity (K_d) value of no more than about 5×10^{-7} M, more preferably no more than about 5×10^{-8} M and, optionally, no more than about $5 \times$

10⁻⁹ M. Generally, the binding affinity of the antibody variant of interest will, like the parent antibody, be in the nanomolar or better range.

One or more of the antibody variants selected from an initial screen are optionally subjected to one or more further biological activity assays to confirm that the antibody variant(s) have improved activity in more than one assay.

Techniques for producing antibodies, which may be the non-human or parent antibody and therefore require modification according to the techniques elaborated herein, follow:

B. Antibody Preparation

(i) Antigen preparation

Soluble antigens or fragments thereof, optionally conjugated to other molecules, can be used as immunogens for generating antibodies. For transmembrane molecules, such as receptors, fragments of these (e.g. the extracellular domain of a receptor) can be used as the immunogen. Alternatively, cells expressing the transmembrane molecule can be used as the immunogen. Such cells can be derived from a natural source (e.g. cancer cell lines) or may be cells which have been transformed by recombinant techniques to express the transmembrane molecule. Other antigens and forms thereof useful for preparing antibodies will be apparent to those in the art.

(ii) Monoclonal antibodies

Monoclonal antibodies may be made using the hybridoma method first described by Kohler et al., *Nature*, 256:495 (1975), or may be made by recombinant DNA methods (U.S. Patent No. 4,816,567).

In the hybridoma method, a mouse or other appropriate host animal, such as a hamster or macaque monkey, is immunized as hereinabove described to elicit lymphocytes that produce or are capable of producing antibodies that will specifically bind to the protein used for immunization. Alternatively, lymphocytes may be immunized *in vitro*. Lymphocytes then are fused with myeloma cells using a suitable fusing agent, such as polyethylene glycol, to form a hybridoma cell (Goding, *Monoclonal Antibodies: Principles and Practice*, pp.59-103 (Academic Press, 1986)).

The hybridoma cells thus prepared are seeded and grown in a

suitable culture medium that preferably contains one or more substances that inhibit the growth or survival of the unfused, parental myeloma cells. For example, if the parental myeloma cells lack the enzyme hypoxanthine guanine phosphoribosyl transferase (HGPRT or HPRT), the culture medium for the hybridomas typically will include hypoxanthine, aminopterin, and thymidine (HAT medium), which substances prevent the growth of HGPRT-deficient cells.

Preferred myeloma cells are those that fuse efficiently, support stable high-level production of antibody by the selected antibody-producing cells, and are sensitive to a medium such as HAT medium. Among these, preferred myeloma cell lines are murine myeloma lines, such as those derived from MOPC-21 and MPC-11 mouse tumors available from the Salk Institute Cell Distribution Center, San Diego, California USA, and SP-2 or X63-Ag8-653 cells available from the American Type Culture Collection, Rockville, Maryland USA. Human myeloma and mouse-human heteromyeloma cell lines also have been described for the production of human monoclonal antibodies (Kozbor, *J. Immunol.*, 133:3001 (1984); Brodeur et al., *Monoclonal Antibody Production Techniques and Applications*, pp. 51-63 (Marcel Dekker, Inc., New York, 1987)).

Culture medium in which hybridoma cells are growing is assayed for production of monoclonal antibodies directed against the antigen. Preferably, the binding specificity of monoclonal antibodies produced by hybridoma cells is determined by immunoprecipitation or by an *in vitro* binding assay, such as radioimmunoassay (RIA) or enzyme-linked immunoabsorbent assay (ELISA).

After hybridoma cells are identified that produce antibodies of the desired specificity, affinity, and/or activity, the clones may be subcloned by limiting dilution procedures and grown by standard methods (Goding, *Monoclonal Antibodies: Principles and Practice*, pp.59-103 (Academic Press, 1986)). Suitable culture media for this purpose include, for example, D-MEM or RPMI-1640 medium. In addition, the hybridoma cells may be grown *in vivo* as ascites tumors in an animal.

The monoclonal antibodies secreted by the subclones are

suitably separated from the culture medium, ascites fluid, or serum by conventional immunoglobulin purification procedures such as, for example, protein A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography.

DNA encoding the monoclonal antibodies is readily isolated and sequenced using conventional procedures (e.g., by using oligonucleotide probes that are capable of binding specifically to genes encoding the heavy and light chains of the monoclonal antibodies). The hybridoma cells serve as a preferred source of such DNA. Once isolated, the DNA may be placed into expression vectors, which are then transfected into host cells such as *E. coli* cells, simian COS cells, Chinese Hamster Ovary (CHO) cells, or myeloma cells that do not otherwise produce immunoglobulin protein, to obtain the synthesis of monoclonal antibodies in the recombinant host cells. Recombinant production of antibodies will be described in more detail below.

In a further embodiment, antibodies or antibody fragments can be isolated from antibody phage libraries generated using the techniques described in McCafferty *et al.*, *Nature*, 348:552-554 (1990). Clackson *et al.*, *Nature*, 352:624-628 (1991) and Marks *et al.*, *J. Mol. Biol.*, 222:581-597 (1991) describe the isolation of murine and human antibodies, respectively, using phage libraries. Subsequent publications describe the production of high affinity (nM range) human antibodies by chain shuffling (Marks *et al.*, *Bio/Technology*, 10:779-783 (1992)), as well as combinatorial infection and *in vivo* recombination as a strategy for constructing very large phage libraries (Waterhouse *et al.*, *Nuc. Acids. Res.*, 21:2265-2266 (1993)). Thus, these techniques are viable alternatives to traditional monoclonal antibody hybridoma techniques for isolation of monoclonal antibodies.

The DNA also may be modified, for example, by substituting the coding sequence for human heavy- and light-chain constant domains in place of the homologous murine sequences (U.S. Patent No. 4,816,567; Morrison *et al.*, *Proc. Natl Acad. Sci. USA*, 81:6851 (1984)), or by covalently joining to the immunoglobulin coding sequence all or part of the coding sequence for a non-

immunoglobulin polypeptide.

Typically such non-immunoglobulin polypeptides are substituted for the constant domains of an antibody, or they are substituted for the variable domains of one antigen-combining site of an antibody to create a chimeric bivalent antibody comprising one antigen-combining site having specificity for an antigen and another antigen-combining site having specificity for a different antigen.

(iii) *Human antibodies*

Transgenic animals (e.g., mice) that are capable, upon immunization, of producing a full repertoire of human antibodies in the absence of endogenous immunoglobulin production are available in the art. For example, it has been described that the homozygous deletion of the antibody heavy-chain joining region (J_H) gene in chimeric and germ-line mutant mice results in complete inhibition of endogenous antibody production. Transfer of the human germ-line immunoglobulin gene array in such germ-line mutant mice will result in the production of human antibodies upon antigen challenge. See, e.g., Jakobovits *et al.*, *Proc. Natl. Acad. Sci. USA*, 90:2551 (1993); Jakobovits *et al.*, *Nature*, 362:255-258 (1993); Bruggermann *et al.*, *Year in Immuno.*, 7:33 (1993); and Duchosal *et al.* *Nature* 355:258 (1992).

Human antibodies can also be derived from phage-display libraries (Hoogenboom *et al.*, *J. Mol. Biol.*, 227:381 (1991); Marks *et al.*, *J. Mol. Biol.*, 222:581-597 (1991); Vaughan *et al.* *Nature Biotech* 14:309 (1996)).

(iv) *Antibody fragments*

Various techniques have been developed for the production of antibody fragments. Traditionally, these fragments were derived via proteolytic digestion of intact antibodies (see, e.g., Morimoto *et al.*, *Journal of Biochemical and Biophysical Methods* 24:107-117 (1992) and Brennan *et al.*, *Science*, 229:81 (1985)). However, these fragments can now be produced directly by recombinant host cells. For example, the antibody fragments can be isolated from the antibody phage libraries discussed above. Alternatively, Fab'-SH fragments can be directly recovered from *E. coli* and chemically coupled to form F(ab')₂ fragments (Carter *et*

al., Bio/Technology 10:163-167 (1992)). According to another approach, F(ab')₂ fragments can be isolated directly from recombinant host cell culture. Other techniques for the production of antibody fragments will be apparent to the skilled practitioner. In other embodiments, the antibody of choice is a single chain Fv fragment (scFv). See WO 93/16185.

(v) *Multispecific antibodies*

Multispecific antibodies have binding specificities for at least two different antigens. While such molecules normally will only bind two antigens (i.e. bispecific antibodies, BsAbs), antibodies with additional specificities such as trispecific antibodies are encompassed by this expression when used herein. Examples of BsAbs include those with one arm directed against a tumor cell antigen and the other arm directed against a cytotoxic trigger molecule such as anti-FcγRI/anti-CD15, anti-p185^{HER2}/FcγRIII (CD16), anti-CD3/anti-malignant B-cell (1D10), anti-CD3/anti-p185^{HER2}, anti-CD3/anti-p97, anti-CD3/anti-renal cell carcinoma, anti-CD3/anti-OVCAR-3, anti-CD3/L-D1 (anti-colon carcinoma), anti-CD3/anti-melanocyte stimulating hormone analog, anti-EGF receptor/anti-CD3, anti-CD3/anti-CAMA1, anti-CD3/anti-CD19, anti-CD3/MoV18, anti-neural cell adhesion molecule (NCAM)/anti-CD3, anti-folate binding protein (FBP)/anti-CD3, anti-pan carcinoma associated antigen (AMOC-31)/anti-CD3; BsAbs with one arm which binds specifically to a tumor antigen and one arm which binds to a toxin such as anti-saporin/anti-Id-1, anti-CD22/anti-saporin, anti-CD7/anti-saporin, anti-CD38/anti-saporin, anti-CEA/anti-ricin A chain, anti-CEA/anti-vinca alkaloid; BsAbs for converting enzyme activated prodrugs such as anti-CD30/anti-alkaline phosphatase (which catalyzes conversion of mitomycin phosphate prodrug to mitomycin alcohol); BsAbs which can be used as fibrinolytic agents such as anti-fibrin/anti-tissue plasminogen activator (tPA), anti-fibrin/anti-urokinase-type plasminogen activator (uPA); BsAbs for targeting immune complexes to cell surface receptors such as anti-low density lipoprotein (LDL)/anti-Fc receptor (e.g. FcγRI, FcγRII or FcγRIII); BsAbs for use in therapy of infectious diseases such as anti-CD3/anti-herpes simplex virus (HSV), anti-T-cell receptor:CD3 complex/anti-

influenza, anti-FcγR/anti-HIV; BsAbs for tumor detection *in vitro* or *in vivo* such as anti-CEA/anti-EOTUBE, anti-CEA/anti-DPTA, anti-p185^{HER2}/anti-hapten; BsAbs as vaccine adjuvants; and BsAbs as diagnostic tools such as anti-rabbit IgG/anti-ferritin, anti-horse
5 radish peroxidase (HRP)/anti-hormone, anti-somatostatin/anti-substance P, anti-HRP/anti-FITC. Examples of trispecific antibodies include anti-CD3/anti-CD4/anti-CD37, anti-CD3/anti-CD5/anti-CD37 and anti-CD3/anti-CD8/anti-CD37. Bispecific antibodies can be prepared as full length antibodies or antibody
10 fragments (e.g. F(ab')₂ bispecific antibodies).

Methods for making bispecific antibodies are known in the art. Traditional production of full length bispecific antibodies is based on the coexpression of two immunoglobulin heavy chain-light chain pairs, where the two chains have different
15 specificities (Millstein *et al.*, *Nature*, 305:537-539 (1983)). Because of the random assortment of immunoglobulin heavy and light chains, these hybridomas (quadromas) produce a potential mixture of 10 different antibody molecules, of which only one has the correct bispecific structure. Purification of the correct
20 molecule, which is usually done by affinity chromatography steps, is rather cumbersome, and the product yields are low. Similar procedures are disclosed in WO 93/08829, and in Traunecker *et al.*, *EMBO J.*, 10:3655-3659 (1991).

According to a different approach, antibody variable domains
25 with the desired binding specificities (antibody-antigen combining sites) are fused to immunoglobulin constant domain sequences. The fusion preferably is with an immunoglobulin heavy chain constant domain, comprising at least part of the hinge, CH2, and CH3 regions. It is preferred to have the first heavy-chain constant
30 region (CH1) containing the site necessary for light chain binding, present in at least one of the fusions. DNAs encoding the immunoglobulin heavy chain fusions and, if desired, the immunoglobulin light chain, are inserted into separate expression vectors, and are co-transfected into a suitable host organism.
35 This provides for great flexibility in adjusting the mutual proportions of the three polypeptide fragments in embodiments when unequal ratios of the three polypeptide chains used in the

construction provide the optimum yields. It is, however, possible to insert the coding sequences for two or all three polypeptide chains in one expression vector when the expression of at least two polypeptide chains in equal ratios results in high yields or
5 when the ratios are of no particular significance.

In a preferred embodiment of this approach, the bispecific antibodies are composed of a hybrid immunoglobulin heavy chain with a first binding specificity in one arm, and a hybrid immunoglobulin heavy chain-light chain pair (providing a second
10 binding specificity) in the other arm. It was found that this asymmetric structure facilitates the separation of the desired bispecific compound from unwanted immunoglobulin chain combinations, as the presence of an immunoglobulin light chain in only one half of the bispecific molecule provides for a facile way
15 of separation. This approach is disclosed in WO 94/04690. For further details of generating bispecific antibodies see, for example, Suresh et al., *Methods in Enzymology*, 121:210 (1986).

According to another approach described in W096/27011, the interface between a pair of antibody molecules can be engineered
20 to maximize the percentage of heterodimers which are recovered from recombinant cell culture. The preferred interface comprises at least a part of the C_H3 domain of an antibody constant domain. In this method, one or more small amino acid side chains from the interface of the first antibody molecule are replaced with larger
25 side chains (e.g. tyrosine or tryptophan). Compensatory "cavities" of identical or similar size to the large side chain(s) are created on the interface of the second antibody molecule by replacing large amino acid side chains with smaller ones (e.g. alanine or threonine). This provides a mechanism for increasing
30 the yield of the heterodimer over other unwanted end-products such as homodimers.

Bispecific antibodies include cross-linked or "heteroconjugate" antibodies. For example, one of the antibodies in the heteroconjugate can be coupled to avidin, the other to
35 biotin. Such antibodies have, for example, been proposed to target immune system cells to unwanted cells (US Patent No. 4,676,980), and for treatment of HIV infection (WO 91/00360, WO

92/200373, and EP 03089). Heteroconjugate antibodies may be made using any convenient cross-linking methods. Suitable cross-linking agents are well known in the art, and are disclosed in US Patent No. 4,676,980, along with a number of cross-linking techniques.

Techniques for generating bispecific antibodies from antibody fragments have also been described in the literature. For example, bispecific antibodies can be prepared using chemical linkage. Brennan et al., *Science*, 229: 81 (1985) describe a procedure wherein intact antibodies are proteolytically cleaved to generate F(ab')₂ fragments. These fragments are reduced in the presence of the dithiol complexing agent sodium arsenite to stabilize vicinal dithiols and prevent intermolecular disulfide formation. The Fab' fragments generated are then converted to thionitrobenzoate (TNB) derivatives. One of the Fab'-TNB derivatives is then reconverted to the Fab'-thiol by reduction with mercaptoethylamine and is mixed with an equimolar amount of the other Fab'-TNB derivative to form the bispecific antibody. The bispecific antibodies produced can be used as agents for the selective immobilization of enzymes.

Various techniques for making and isolating bispecific antibody fragments directly from recombinant cell culture have also been described. For example, bispecific antibodies have been produced using leucine zippers. Kostelny et al., *J. Immunol.*, 148(5):1547-1553 (1992). The leucine zipper peptides from the Fos and Jun proteins were linked to the Fab' portions of two different antibodies by gene fusion. The antibody homodimers were reduced at the hinge region to form monomers and then re-oxidized to form the antibody heterodimers. This method can also be utilized for the production of antibody homodimers. The "diabody" technology described by Hollinger et al., *Proc. Natl. Acad. Sci. USA*, 90:6444-6448 (1993) has provided an alternative mechanism for making bispecific antibody fragments. The fragments comprise a heavy-chain variable domain (V_H) connected to a light-chain variable domain (V_L) by a linker which is too short to allow pairing between the two domains on the same chain. Accordingly,

the V_H and V_L domains of one fragment are forced to pair with the complementary V_L and V_H domains of another fragment, thereby forming two antigen-binding sites. Another strategy for making bispecific antibody fragments by the use of single-chain Fv (sFv) dimers has also been reported. See Gruber *et al.*, *J. Immunol.*, 152:5368 (1994).

Antibodies with more than two valencies are contemplated. For example, trispecific antibodies can be prepared. Tutt *et al.* *J. Immunol.* 147: 60 (1991).

10 (vi) *Effector function engineering*

It may be desirable to modify the antibody of the invention with respect to effector function, so as to enhance the effectiveness of the antibody in treating cancer, for example. For example cysteine residue(s) may be introduced in the Fc region, thereby allowing interchain disulfide bond formation in this region. The homodimeric antibody thus generated may have improved internalization capability and/or increased complement-mediated cell killing and antibody-dependent cellular cytotoxicity (ADCC). See Caron *et al.*, *J. Exp Med.* 176:1191-1195 (1992) and Shopes, B. *J. Immunol.* 148:2918-2922 (1992). Homodimeric antibodies with enhanced anti-tumor activity may also be prepared using heterobifunctional cross-linkers as described in Wolff *et al.* *Cancer Research* 53:2560-2565 (1993). Alternatively, an antibody can be engineered which has dual Fc regions and may thereby have enhanced complement lysis and ADCC capabilities. See Stevenson *et al.* *Anti-Cancer Drug Design* 3:219-230 (1989).

WO00/42072 (Presta, L.) describes antibodies with improved ADCC function in the presence of human effector cells, where the antibodies comprise amino acid substitutions in the Fc region thereof. An especially preferred variant has amino acid substitutions at positions 298, 333 and 334 of the Fc region, and improved ADCC function.

Antibodies with altered C1q binding and/or complement dependent cytotoxicity (CDC) are described in WO99/51642, US Patent No. 6,194,551B1, US Patent No. 6,242,195B1, US Patent No. 6,528,624B1 and US Patent No. 6,538,124 (Idusogie *et al.*). The

antibodies comprise an amino acid substitution at one or more of amino acid positions 270, 322, 326, 327, 329, 313, 333 and/or 334 of the Fc region thereof.

(vii) *Conjugates and other modifications of the altered antibody*

The antibody variant herein is optionally conjugated to a cytotoxic agent.

Chemotherapeutic agents useful in the generation of such antibody variant-cytotoxic agent conjugates have been described above.

Conjugates of an antibody variant and one or more small molecule toxins, such as a calicheamicin, a maytansine (US Patent No. 5,208,020), a trichothene, and CC1065 are also contemplated herein. In one embodiment of the invention, the antibody variant is conjugated to one or more maytansine molecules (e.g. about 1 to about 10 maytansine molecules per antibody variant molecule). Maytansine may, for example, be converted to May-SS-Me which may be reduced to May-SH3 and reacted with modified antibody variant (Chari et al. *Cancer Research* 52: 127-131 (1992)) to generate a maytansinoid-antibody variant conjugate.

Alternatively, the antibody variant is conjugated to one or more calicheamicin molecules. The calicheamicin family of antibiotics are capable of producing double-stranded DNA breaks at sub-picomolar concentrations. Structural analogues of calicheamicin which may be used include, but are not limited to, γ_1^I , α_2^I , α_3^I , N-acetyl- γ_1^I , PSAG and θ_1^I (Hinman et al. *Cancer Research* 53: 3336-3342 (1993) and Lode et al. *Cancer Research* 58: 2925-2928 (1998)).

Enzymatically active toxins and fragments thereof which can be used include diphtheria A chain, nonbinding active fragments of diphtheria toxin, exotoxin A chain (from *Pseudomonas aeruginosa*), ricin A chain, abrin A chain, modeccin A chain, alpha-sarcin, *Aleurites fordii* proteins, dianthin proteins, *Phytolaca americana* proteins (PAPI, PAPII, and PAP-S), momordica charantia inhibitor, curcin, crotin, *Saponaaria officinalis* inhibitor, gelonin, mitogellin, restrictocin, phenomycin, enomycin and the tricothecenes. See, for example, WO 93/21232 published October

28, 1993.

The present invention further contemplates antibody variant conjugated with a compound with nucleolytic activity (e.g. a ribonuclease or a DNA endonuclease such as a deoxyribonuclease; DNase).

A variety of radioactive isotopes are available for the production of radioconjugated antibody variants. Examples include At^{211} , I^{131} , I^{125} , Y^{90} , Re^{186} , Re^{188} , Sm^{153} , Bi^{212} , P^{32} and radioactive isotopes of Lu.

Conjugates of the antibody variant and cytotoxic agent may be made using a variety of bifunctional protein coupling agents such as N-succinimidyl-3-(2-pyridyldithiol) propionate (SPDP), succinimidyl-4-(N-maleimidomethyl) cyclohexane-1-carboxylate, iminothiolane (IT), bifunctional derivatives of imidoesters (such as dimethyl adipimidate HCL), active esters (such as disuccinimidyl suberate), aldehydes (such as glutaraldehyde), bis-azido compounds (such as bis (p-azidobenzoyl) hexanediamine), bis-diazonium derivatives (such as bis-(p-diazoniumbenzoyl)-ethylenediamine), diisocyanates (such as tolyene 2,6-diisocyanate), and bis-active fluorine compounds (such as 1,5-difluoro-2,4-dinitrobenzene). For example, a ricin immunotoxin can be prepared as described in Vitetta et al. *Science* 238: 1098 (1987). Carbon-14-labeled 1-isothiocyanatobenzyl-3-methyldiethylene triaminepentaacetic acid (MX-DTPA) is an exemplary chelating agent for conjugation of radionucleotide to the antibody variant. See WO94/11026. The linker may be a "cleavable linker" facilitating release of the cytotoxic drug in the cell. For example, an acid-labile linker, peptidase-sensitive linker, dimethyl linker or disulfide-containing linker (Chari et al. *Cancer Research* 52: 127-131 (1992)) may be used.

Alternatively, a fusion protein comprising the antibody variant and cytotoxic agent may be made, e.g. by recombinant techniques or peptide synthesis.

The antibody variants of the present invention may also be conjugated with a prodrug-activating enzyme which converts a prodrug (e.g. a peptidyl chemotherapeutic agent, see WO81/01145) to an active anti-cancer drug. See, for example, WO 88/07378 and

U.S. Patent No. 4,975,278. The enzyme component of such conjugates includes any enzyme capable of acting on a prodrug in such a way so as to covert it into its more active, cytotoxic form. Enzymes that are useful in the method of this invention include, but are not limited to, alkaline phosphatase useful for converting phosphate-containing prodrugs into free drugs; arylsulfatase useful for converting sulfate-containing prodrugs into free drugs; cytosine deaminase useful for converting non-toxic 5-fluorocytosine into the anti-cancer drug, 5-fluorouracil; proteases, such as serratia protease, thermolysin, subtilisin, carboxypeptidases and cathepsins (such as cathepsins B and L), that are useful for converting peptide-containing prodrugs into free drugs; D-alanylcarboxypeptidases, useful for converting prodrugs that contain D-amino acid substituents; carbohydrate-cleaving enzymes such as β -galactosidase and neuraminidase useful for converting glycosylated prodrugs into free drugs; β -lactamase useful for converting drugs derivatized with β -lactams into free drugs; and penicillin amidases, such as penicillin V amidase or penicillin G amidase, useful for converting drugs derivatized at their amine nitrogens with phenoxyacetyl or phenylacetyl groups, respectively, into free drugs. Alternatively, antibodies with enzymatic activity, also known in the art as "abzymes", can be used to convert the prodrugs of the invention into free active drugs (see, e.g., Massey, *Nature* 328: 457-458 (1987)). Antibody variant-abzyme conjugates can be prepared as described herein for delivery of the abzyme to a tumor cell population. The enzymes of this invention can be covalently bound to the antibody variant by techniques well known in the art such as the use of the heterobifunctional crosslinking reagents discussed above.

Alternatively, fusion proteins comprising at least the antigen binding region of an antibody variant of the invention linked to at least a functionally active portion of an enzyme of the invention can be constructed using recombinant DNA techniques well known in the art (see, e.g., Neuberger et al., *Nature*, 312: 604-608 (1984)).

Other modifications of the antibody variant are contemplated herein. For example, the antibody variant may be linked to one of

a variety of nonproteinaceous polymers, e.g., polyethylene glycol (PEG), polypropylene glycol, polyoxyalkylenes, or copolymers of polyethylene glycol and polypropylene glycol. Antibody fragments, such as Fab', linked to one or more PEG molecules are
5 an especially preferred embodiment of the invention.

The antibody variants disclosed herein may also be formulated as liposomes. Liposomes containing the antibody variant are prepared by methods known in the art, such as described in Epstein et al., *Proc. Natl. Acad. Sci. USA*, 82:3688 (1985); Hwang et al.,
10 *Proc. Natl. Acad. Sci. USA*, 77:4030 (1980); U.S. Pat. Nos. 4,485,045 and 4,544,545; and WO97/38731 published October 23, 1997. Liposomes with enhanced circulation time are disclosed in U.S. Patent No. 5,013,556. Particularly useful liposomes can be generated by the reverse phase evaporation method with a lipid
15 composition comprising phosphatidylcholine, cholesterol and PEG-derivatized phosphatidylethanolamine (PEG-PE). Liposomes are extruded through filters of defined pore size to yield liposomes with the desired diameter. Fab' fragments of an antibody of the present invention can be conjugated to the liposomes as described
20 in Martin et al. *J. Biol. Chem.* 257: 286-288 (1982) via a disulfide interchange reaction. A chemotherapeutic agent is optionally contained within the liposome. See Gabizon et al. *J. National Cancer Inst.* 81(19)1484 (1989).

To increase the serum half life of the antagonist, one may
25 incorporate a salvage receptor binding epitope into the antagonist (especially an antibody fragment) as described in US Patent 5,739,277, for example. As used herein, the term "salvage receptor binding epitope" refers to an epitope of the Fc region of an IgG molecule (e.g., IgG₁, IgG₂, IgG₃, or IgG₄) that is
30 responsible for increasing the *in vivo* serum half-life of the IgG molecule. Antibodies with substitutions in an Fc region thereof and increased serum half-lives are also described in WO00/42072 (Presta, L.).

Engineered antibodies with three or more (preferably four)
35 functional antigen binding sites are also contemplated (US Appln No. US2002/0004587 A1, Miller et al.).

(viii) Glycosylation variants

Another type of amino acid variant of the antagonist alters the original glycosylation pattern of the antagonist. Such altering includes deleting one or more carbohydrate moieties found in the antagonist, and/or adding one or more glycosylation sites that are not present in the antagonist.

Glycosylation of polypeptides is typically either N-linked or O-linked. N-linked refers to the attachment of the carbohydrate moiety to the side chain of an asparagine residue. The tripeptide sequences asparagine-X-serine and asparagine-X-threonine, where X is any amino acid except proline, are the recognition sequences for enzymatic attachment of the carbohydrate moiety to the asparagine side chain. Thus, the presence of either of these tripeptide sequences in a polypeptide creates a potential glycosylation site. O-linked glycosylation refers to the attachment of one of the sugars N-acetylglucosamine, galactose, or xylose to a hydroxyamino acid, most commonly serine or threonine, although 5-hydroxyproline or 5-hydroxylysine may also be used.

Addition of glycosylation sites to the antagonist is conveniently accomplished by altering the amino acid sequence such that it contains one or more of the above-described tripeptide sequences (for N-linked glycosylation sites). The alteration may also be made by the addition of, or substitution by, one or more serine or threonine residues to the sequence of the original antagonist (for O-linked glycosylation sites).

Where the antibody comprises an Fc region, the carbohydrate attached thereto may be altered. For example, antibodies with a mature carbohydrate structure which lacks fucose attached to an Fc region of the antibody are described in US Pat Appl No US 2003/0157108 A1, Presta, L. Antibodies with a bisecting N-acetylglucosamine (GlcNAc) in the carbohydrate attached to an Fc region of the antibody are referenced in WO03/011878, Jean-Mairet *et al.* and US Patent No. 6,602,684, Umana *et al.* Antibodies with at least one galactose residue in the oligosaccharide attached to an Fc region of the antibody are reported in WO97/30087, Patel *et al.* See, also, WO98/58964 (Raju, S.) and WO99/22764 (Raju, S.) concerning antibodies with altered carbohydrate attached to the Fc

region thereof.

C. Pharmaceutical Formulations

Therapeutic formulations of the antibody variant are prepared for storage by mixing the antibody variant having the desired
5 degree of purity with optional physiologically acceptable carriers, excipients or stabilizers (*Remington's Pharmaceutical Sciences* 16th edition, Osol, A. Ed. (1980)), in the form of lyophilized formulations or aqueous solutions. Acceptable carriers, excipients, or stabilizers are nontoxic to recipients at
10 the dosages and concentrations employed, and include buffers such as phosphate, citrate, and other organic acids; antioxidants including ascorbic acid and methionine; preservatives (such as octadecyldimethylbenzyl ammonium chloride; hexamethonium chloride; benzalkonium chloride, benzethonium chloride; phenol, butyl or
15 benzyl alcohol; alkyl parabens such as methyl or propyl paraben; catechol; resorcinol; cyclohexanol; 3-pentanol; and m-cresol); low molecular weight (less than about 10 residues) polypeptide; proteins, such as serum albumin, gelatin, or immunoglobulins; hydrophilic polymers such as polyvinylpyrrolidone; amino acids
20 such as glycine, glutamine, asparagine, histidine, arginine, or lysine; monosaccharides, disaccharides, and other carbohydrates including glucose, mannose, or dextrans; chelating agents such as EDTA; sugars such as sucrose, mannitol, trehalose or sorbitol; salt-forming counter-ions such as sodium; metal complexes (e.g.,
25 Zn-protein complexes); and/or non-ionic surfactants such as TWEEN™, PLURONICS™ or polyethylene glycol (PEG).

The formulation herein may also contain more than one active compound as necessary for the particular indication being treated, preferably those with complementary activities that do not
30 adversely affect each other. For example, it may be desirable to further provide an immunosuppressive agent. Such molecules are suitably present in combination in amounts that are effective for the purpose intended.

The active ingredients may also be entrapped in microcapsule
35 prepared, for example, by coacervation techniques or by interfacial polymerization, for example, hydroxymethylcellulose or gelatin-microcapsule and poly-(methylmethacrylate) microcapsule,

respectively, in colloidal drug delivery systems (for example, liposomes, albumin microspheres, microemulsions, nano-particles and nanocapsules) or in macroemulsions. Such techniques are disclosed in *Remington's Pharmaceutical Sciences* 16th edition,
5 Osol, A. Ed. (1980).

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

Sustained-release preparations may be prepared. Suitable
10 examples of sustained-release preparations include semipermeable matrices of solid hydrophobic polymers containing the antibody variant, which matrices are in the form of shaped articles, e.g., films, or microcapsule. Examples of sustained-release matrices include polyesters, hydrogels (for example, poly(2-hydroxyethyl-methacrylate), or poly(vinylalcohol)), polylactides (U.S. Pat. No.
15 3,773,919), copolymers of L-glutamic acid and ethyl-L-glutamate, non-degradable ethylene-vinyl acetate, degradable lactic acid-glycolic acid copolymers such as the LUPRON DEPOT™ (injectable microspheres composed of lactic acid-glycolic acid copolymer and
20 leuprolide acetate), and poly-D-(-)-3-hydroxybutyric acid. While polymers such as ethylene-vinyl acetate and lactic acid-glycolic acid enable release of molecules for over 100 days, certain hydrogels release proteins for shorter time periods. When encapsulated antibodies remain in the body for a long time, they
25 may denature or aggregate as a result of exposure to moisture at 37°C, resulting in a loss of biological activity and possible changes in immunogenicity. Rational strategies can be devised for stabilization depending on the mechanism involved. For example, if the aggregation mechanism is discovered to be intermolecular S-S bond formation through thio-disulfide interchange, stabilization
30 may be achieved by modifying sulfhydryl residues, lyophilizing from acidic solutions, controlling moisture content, using appropriate additives, and developing specific polymer matrix compositions.

35 D. Non-Therapeutic Uses for the Antibody Variant

The antibody variants of the invention may be used as affinity purification agents. In this process, the antibodies are

immobilized on a solid phase such a Sephadex resin or filter paper, using methods well known in the art. The immobilized antibody variant is contacted with a sample containing the antigen to be purified, and thereafter the support is washed with a
5 suitable solvent that will remove substantially all the material in the sample except the antigen to be purified, which is bound to the immobilized antibody variant. Finally, the support is washed with another suitable solvent, such as glycine buffer, pH 5.0, that will release the antigen from the antibody variant.

10 The variant antibodies may also be useful in diagnostic assays, e.g., for detecting expression of an antigen of interest in specific cells, tissues, or serum.

For diagnostic applications, the antibody variant typically will be labeled with a detectable moiety. Numerous labels are
15 available which can be generally grouped into the following categories:

(a) Radioisotopes, such as ^{35}S , ^{14}C , ^{125}I , ^3H , and ^{131}I . The antibody variant can be labeled with the radioisotope using the techniques described in *Current Protocols in Immunology*, Volumes 1
20 and 2, Coligen et al., Ed. Wiley-Interscience, New York, New York, Pubs. (1991) for example and radioactivity can be measured using scintillation counting.

(b) Fluorescent labels such as rare earth chelates (europium chelates) or fluorescein and its derivatives, rhodamine and its
25 derivatives, dansyl, Lissamine, phycoerythrin and Texas Red are available. The fluorescent labels can be conjugated to the antibody variant using the techniques disclosed in *Current Protocols in Immunology*, supra, for example. Fluorescence can be quantified using a fluorimeter.

30 (c) Various enzyme-substrate labels are available and U.S. Patent No. 4,275,149 provides a review of some of these. The enzyme generally catalyzes a chemical alteration of the chromogenic substrate which can be measured using various techniques. For example, the enzyme may catalyze a color change in
35 a substrate, which can be measured spectrophotometrically. Alternatively, the enzyme may alter the fluorescence or chemiluminescence of the substrate. Techniques for quantifying a

change in fluorescence are described above. The chemiluminescent substrate becomes electronically excited by a chemical reaction and may then emit light which can be measured (using a chemiluminometer, for example) or donates energy to a fluorescent acceptor. Examples of enzymatic labels include luciferases (e.g., firefly luciferase and bacterial luciferase; U.S. Patent No. 4,737,456), luciferin, 2,3-dihydrophthalazinediones, malate dehydrogenase, urease, peroxidase such as horseradish peroxidase (HRPO), alkaline phosphatase, beta-galactosidase, glucoamylase, lysozyme, saccharide oxidases (e.g., glucose oxidase, galactose oxidase, and glucose-6-phosphate dehydrogenase), heterocyclic oxidases (such as uricase and xanthine oxidase), lactoperoxidase, microperoxidase, and the like. Techniques for conjugating enzymes to antibodies are described in O'Sullivan et al., *Methods for the Preparation of Enzyme-Antibody Conjugates for use in Enzyme Immunoassay*, in *Methods in Enzym.* (ed J. Langone & H. Van Vunakis), Academic press, New York, 73:147-166 (1981).

Examples of enzyme-substrate combinations include, for example:

(i) Horseradish peroxidase (HRPO) with hydrogen peroxidase as a substrate, wherein the hydrogen peroxidase oxidizes a dye precursor (e.g., orthophenylene diamine (OPD) or 3,3',5,5'-tetramethyl benzidine hydrochloride (TMB));

(ii) alkaline phosphatase (AP) with para-Nitrophenyl phosphate as chromogenic substrate; and

(iii) beta-D-galactosidase (beta-D-Gal) with a chromogenic substrate (e.g., p-nitrophenyl-beta-D-galactosidase) or fluorogenic substrate 4-methylumbelliferyl-beta-D-galactosidase.

Numerous other enzyme-substrate combinations are available to those skilled in the art. For a general review of these, see U.S. Patent Nos. 4,275,149 and 4,318,980.

Sometimes, the label is indirectly conjugated with the antibody variant. The skilled artisan will be aware of various techniques for achieving this. For example, the antibody variant can be conjugated with biotin and any of the three broad categories of labels mentioned above can be conjugated with avidin, or vice versa. Biotin binds selectively to avidin and

thus, the label can be conjugated with the antibody variant in this indirect manner. Alternatively, to achieve indirect conjugation of the label with the antibody variant, the antibody variant is conjugated with a small hapten (e.g., digoxin) and one of the different types of labels mentioned above is conjugated with an anti-hapten antibody variant (e.g., anti-digoxin antibody). Thus, indirect conjugation of the label with the antibody variant can be achieved.

In another embodiment of the invention, the antibody variant need not be labeled, and the presence thereof can be detected using a labeled antibody which binds to the antibody variant.

The antibodies of the present invention may be employed in any known assay method, such as competitive binding assays, direct and indirect sandwich assays, and immunoprecipitation assays. Zola, *Monoclonal Antibodies: A Manual of Techniques*, pp.147-158 (CRC Press, Inc. 1987).

Competitive binding assays rely on the ability of a labeled standard to compete with the test sample analyze for binding with a limited amount of antibody variant. The amount of antigen in the test sample is inversely proportional to the amount of standard that becomes bound to the antibodies. To facilitate determining the amount of standard that becomes bound, the antibodies generally are insolubilized before or after the competition, so that the standard and analyze that are bound to the antibodies may conveniently be separated from the standard and analyze which remain unbound.

Sandwich assays involve the use of two antibodies, each capable of binding to a different immunogenic portion, or epitope, of the protein to be detected. In a sandwich assay, the test sample analyze is bound by a first antibody which is immobilized on a solid support, and thereafter a second antibody binds to the analyze, thus forming an insoluble three-part complex. See, e.g., US Pat No. 4,376,110. The second antibody may itself be labeled with a detectable moiety (direct sandwich assays) or may be measured using an anti-immunoglobulin antibody that is labeled with a detectable moiety (indirect sandwich assay). For example, one type of sandwich assay is an ELISA assay, in which case the

detectable moiety is an enzyme.

For immunohistochemistry, the tumor sample may be fresh or frozen or may be embedded in paraffin and fixed with a preservative such as formalin, for example.

5 The antibodies may also be used for *in vivo* diagnostic assays. Generally, the antibody variant is labeled with a radionuclide (such as ¹¹¹In, ⁹⁹Tc, ¹⁴C, ¹³¹I, ¹²⁵I, ³H, ³²P or ³⁵S) so that the tumor can be localized using immunoscintigraphy.

E. Diagnostic Kits

10 As a matter of convenience, the antibody variant of the present invention can be provided in a kit, *i.e.*, a packaged combination of reagents in predetermined amounts with instructions for performing the diagnostic assay. Where the antibody variant is labeled with an enzyme, the kit will include substrates and
15 cofactors required by the enzyme (e.g., a substrate precursor which provides the detectable chromophore or fluorophore). In addition, other additives may be included such as stabilizers, buffers (e.g., a block buffer or lysis buffer) and the like. The relative amounts of the various reagents may be varied widely to
20 provide for concentrations in solution of the reagents which substantially optimize the sensitivity of the assay. Particularly, the reagents may be provided as dry powders, usually lyophilized, including excipients which on dissolution will provide a reagent solution having the appropriate concentration.

F. In Vivo Uses for the Antibody Variant

25 For therapeutic applications, the antibody variants of the invention are administered to a mammal, preferably a human, in a pharmaceutically acceptable dosage form such as those discussed above, including those that may be administered to a human
30 intravenously as a bolus or by continuous infusion over a period of time, by intramuscular, intraperitoneal, intra-cerebrospinal, subcutaneous, intra-articular, intrasynovial, intrathecal, oral, topical, or inhalation routes. The antibodies also are suitably administered by intra-tumoral, peri-tumoral, intra-lesional, or
35 peri-lesional routes, to exert local as well as systemic therapeutic effects. In addition, the antibody variant is suitably administered by pulse infusion, particularly with

declining doses of the antibody variant. Preferably the dosing is given by injections, most preferably intravenous or subcutaneous injections, depending in part on whether the administration is brief or chronic.

5 With respect to the exemplified antibodies, IgE antibodies may be used to treat IgE-mediated disorders (see definitions above), including allergic asthma. LFA-1 or CD11a antibodies may be used to treat LFA-1 mediated disorders or autoimmune diseases including those listed above in the definitions section, but
10 especially psoriasis, psoriatic arthritis, atopic dermatitis, multiple sclerosis, Crohn's disease, lupus, ankylosing spondylitis, organ transplant and rheumatoid arthritis. Tissue factor (TF) antibodies can be used to block binding of TF to Factor VII and/or Factor X. TF antibodies may treat
15 hypercoagulable states, cancer, and inflammatory diseases, including the specific indications encompassed by these diseases or disorders as listed in the definitions section above.

For the prevention or treatment of disease, the appropriate dosage of antibody variant will depend on the type of disease to
20 be treated, the severity and course of the disease, whether the antibody variant is administered for preventive or therapeutic purposes, previous therapy, the patient's clinical history and response to the antibody variant, and the discretion of the attending physician. The antibody variant is suitably
25 administered to the patient at one time or over a series of treatments.

Depending on the type and severity of the disease, about 1 µg/kg to 15 mg/kg (e.g., 0.1-20mg/kg) of antibody variant is an initial candidate dosage for administration to the patient,
30 whether, for example, by one or more separate administrations, or by continuous infusion. A typical daily dosage might range from about 1 µg/kg to 100 mg/kg or more, depending on the factors mentioned above. For repeated administrations over several days or longer, depending on the condition, the treatment is sustained
35 until a desired suppression of disease symptoms occurs. However, other dosage regimens may be useful. The progress of this therapy is easily monitored by conventional techniques and assays.

The antibody variant composition will be formulated, dosed, and administered in a fashion consistent with good medical practice. Factors for consideration in this context include the particular disorder being treated, the particular mammal being
5 treated, the clinical condition of the individual patient, the cause of the disorder, the site of delivery of the agent, the method of administration, the scheduling of administration, and other factors known to medical practitioners.

The "therapeutically effective amount" of the antibody
10 variant to be administered will be governed by such considerations, and is the minimum amount necessary to prevent, ameliorate, or treat a disease or disorder. The antibody variant need not be, but is optionally formulated with one or more agents currently used to prevent or treat the disorder in question. The
15 effective amount of such other agents depends on the amount of antibody variant present in the formulation, the type of disorder or treatment, and other factors discussed above. These are generally used in the same dosages and with administration routes as used hereinbefore or about from 1 to 99% of the heretofore
20 employed dosages.

G. Articles of Manufacture

In another embodiment of the invention, an article of manufacture containing materials useful for the treatment of the disorders described above is provided. The article of manufacture
25 comprises a container and a label. Suitable containers include, for example, bottles, vials, syringes, and test tubes. The containers may be formed from a variety of materials such as glass or plastic. The container holds a composition which is effective for treating the condition and may have a sterile access port (for
30 example the container may be an intravenous solution bag or a vial having a stopper pierceable by a hypodermic injection needle). The active agent in the composition is the antibody variant. The label on, or associated with, the container indicates that the composition is used for treating the condition of choice. The
35 article of manufacture may further comprise a second container comprising a pharmaceutically-acceptable buffer, such as phosphate-buffered saline, Ringer's solution and dextrose

solution. It may further include other materials desirable from a commercial and user standpoint, including other buffers, diluents, filters, needles, syringes, and package inserts with instructions for use.

5

EXAMPLES

The examples herein demonstrate the applicability of the method of CDR-repairing for antibodies directed against three different antigens, namely tissue factor (TF), immunoglobulin E (IgE), and CD11a.

10

Materials and Methods

Residue numbers are according to Kabat (Kabat et al., *Sequences of proteins of immunological interest*, 5th Ed., Public Health Service, National Institutes of Health, Bethesda, MD (1991)). Single letter amino acid abbreviations are used. DNA degeneracies are represented using the IUB code (N = A/C/G/T, D = A/G/T, V = A/C/G, B = C/G/T, H = A/C/T, K = G/T, M = A/C, R = A/G, S = G/C, W = A/T, Y = C/T).

15

20

Direct hypervariable region grafts onto the acceptor human consensus framework - The phagemid used for this work is a monovalent Fab-g3 display vector and consists of 2 open reading frames under control of the phoA promoter. The first open reading frame consists of the stII signal sequence fused to the acceptor light chain and the second consists of the stII signal sequence fused to the VH and CH1 domains of acceptor followed by the minor phage coat protein P3.

25

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The VL and VH domains from murine antibodies to be humanized were aligned with the human consensus VL domain and the acceptor VH domain. The acceptor VH framework differs from the human consensus VH domain at 3 positions: R71A, N73T, and L78A (Carter et al., *Proc. Natl. Acad. Sci. USA* 89:4285 (1992)). Hypervariable regions from the murine antibody were engineered into the acceptor human consensus framework to generate a direct-graft of the murine antibody. In the VL domain the following regions were grafted to the human consensus acceptor: positions 24-34 (L1), 50-56 (L2) and 89-97 (L3). In the VH domain, positions 26-35 (H1), 49-65 (H2) and

93-102 (H3) were grafted (Figures 1A-1B).

The direct-graft variants were generated by Kunkel mutagenesis using a separate oligonucleotide for each hypervariable region. Correct clones were assessed by DNA sequencing.

Soft randomization of the hypervariable regions - Sequence diversity was introduced into each hypervariable region using a soft randomization strategy that maintains a bias towards the murine hypervariable region sequence. This was accomplished using a poisoned oligonucleotide synthesis strategy first described by Gallop et al., *J. Med. Chem.* 37:1233-1251 (1994). For a given position within a hypervariable region to be mutated, the codon encoding the wild-type amino acid is poisoned with a 70-10-10-10 mixture of nucleotides resulting in an average 50 percent mutation rate at each position.

Soft randomized oligonucleotides were patterned after the murine hypervariable region sequences and encompassed the same regions defined by the direct hypervariable region grafts. Only two positions, amino acids at the beginning of H2 and H3 in the VH domain, were limited in their diversity. The codon RGC was used for position 49 encoding A, G, S or T and at position 94, the codon ARA was used encoding R or K.

Generation of phage libraries - Randomized oligonucleotide pools designed for each hypervariable region were phosphorylated separately in six 20 µl reactions containing 660 ng of oligonucleotide, 50 mM Tris pH 7.5, 10 mM MgCl₂, 1 mM ATP, 20 mM DTT, and 5 U polynucleotide kinase for 1 h at 37°C. The six phosphorylated oligonucleotide pools were then combined with 20 µg of Kunkel template in 50 mM Tris pH 7.5, 10 mM MgCl₂ in a final volume of 500 µl resulting in a oligonucleotide to template ratio of 3. The mixture was annealed at 90 °C for 4 min, 50 °C for 5 min and then cooled on ice. Excess, unannealed oligonucleotide was removed with a QIAQUICK PCR purification kit (Qiagen kit 28106) using a modified protocol to prevent excessive denaturation of the annealed DNA. To the 500 µl of annealed mixture, 150 µl of PB was added, and the mixture was split between 2 silica columns.

Following a wash of each column with 750 μ l of PE and an extra spin to dry the columns, each column was eluted with 110 μ l of 10 mM Tris, 1 mM EDTA, pH 8. The annealed and cleaned-up template (220 μ l) was then filled in by adding 1 μ l 100mM ATP, 10 μ l 25mM dNTPs (25mM each of dATP, dCTP, dGTP and dTTP), 15 μ l 100mM DTT, 25 μ l 10X TM buffer (0.5 M Tris pH 7.5, 0.1 M $MgCl_2$), 2400 U T4 ligase, and 30 U T7 polymerase for 3 h at room temperature.

The filled in product was analyzed on Tris-Acetate-EDTA/agarose gels (Sidhu et al., *Methods in Enzymology* 328:333-363 (2000)). Three bands are usually visible: the bottom band is correctly filled and ligated product, the middle band is filled but unligated and the top band is strand displaced. The top band is produced by an intrinsic side activity of T7 polymerase and is difficult to avoid (Lechner et al., *J. Biol. Chem.* 258:11174-11184 (1983)); however, this band transforms 30-fold less efficiently than the top band and usually contributes little to the library. The middle band is due to the absence of a 5' phosphate for the final ligation reaction; this band transforms efficiently and unfortunately, gives mainly wild type sequence.

The filled in product was then cleaned-up and electroporated into SS320 cells and propagated in the presence of M13/KO7 helper phage as described by Sidhu et al., *Methods in Enzymology* 328:333-363 (2000). Library sizes ranged from 1 - 2 x 10⁹ independent clones. Random clones from the initial libraries were sequenced to assess library quality.

Phage Selection - Human LFA-1, IgE or TF were coated on MaxiSorp microtiter plates (Nunc) at 5 μ g/ml in PBS. For the first round of selection 8 wells of target were used; a single well of target was used for successive rounds of selection. Wells were blocked for 1 h using Casein Blocker (Pierce). Phage were harvested from the culture supernatant and suspended in PBS containing 1 % BSA and 0.05 % TWEEN 20 (PBSBT). After binding to the wells for 2 h, unbound phage were removed by extensive washing with PBS containing 0.05 % TWEEN 20 (PBST). Bound phage were eluted by incubating the wells with 50 mM HCl, 0.5 M KCl for 30 min. Phage were amplified using Top10 cells and M13/KO7 helper

phage and grown overnight at 37 °C in 2YT, 50 µg/ml carbanacillin. The titers of phage eluted from a target coated well were compared to titers of phage recovered from a non-target coated well to assess enrichment.

5 **Phage ELISA**. - MaxiSorp microtiter plates were coated with human LFA-1, IgE or TF at 5 µg/ml in PBS over night and then blocked with Casein Blocker. Phage from culture supernatants were incubated with serially diluted LFA-1, IgE or TF in PBSBT in a tissue culture microtiter plate for 1 h after which 80 µl of the
10 mixture was transferred to the target coated wells for 15 min to capture unbound phage. The plate was washed with PBST and HRP conjugated anti-M13 (Amersham Pharmacia Biotech) was added (1:5000 in PBSBT) for 40 min. The plate was washed with PBST and developed by adding Tetramethylbenzidine substrate (Kirkegaard and Perry
15 Laboratories, Gaithersburg, MD). The absorbance at 405 nm was plotted as a function of target concentration in solution to determine an IC₅₀. This was used as an affinity estimate for the Fab clone displayed on the surface of the phage.

20

RESULTS

Generation of large phage libraries using multiple oligonucleotides

The potential sequence diversity encompassed in a strategy to completely randomize over 60 positions represented by the 6 hypervariable regions of an antibody is huge, far beyond the
25 capacity of any library screening method. Further, complete randomization of the hypervariable regions would likely result in a change of the antigen epitope recognized by the antibody. To solve both of these problems a soft randomization strategy was used that maintained a bias towards the murine hypervariable
30 region sequence while introducing a 50 percent mutation rate at each selected position.

Large phage display libraries have been generated using the method described by Sidhu (Sidhu et al., *Methods in Enzymology* 328:333-363 (2000)). Unfortunately as the number of
35 oligonucleotides in a Kunkel mutagenesis reaction increases the frequency of clones containing all mutagenic oligonucleotides decreases. To compensate for this, one could increase the

oligonucleotide concentration to ensure that all sites are fully occupied during the annealing process; however, as the concentration of oligonucleotides in the polymerase reaction increases, the potential for side reactions also increases
5 resulting in a decreased yield of mutagenized clones and an overall reduced library size.

This problem was overcome by adding a clean-up step to remove excess un-annealed oligonucleotides prior to the polymerase reaction. The QIAQUICK PCR purification kit is designed to remove
10 single stranded DNA of less than 100 base pairs. A reagent, PB, is added to facilitate double stranded DNA binding to the silica matrix. While single stranded Kunkel template DNA would be expected to bind to the silica in the presence of reagent, high concentrations of reagent had the potential to dislodge bound
15 oligonucleotides that were annealed to the template. In order to determine the minimum amount of reagent required for template binding to the silica column, the binding of DNA to the silica column was followed as a function of the reagent (PB) concentration provided in the purification kit (Figure 2). As
20 expected, in the presence of PB, an 81 base pair oligonucleotide did not interact with the silica column. The fraction of double stranded phagemid DNA that bound to the silica increased at higher concentrations of PB; however, only a quarter volume of PB was sufficient to attain significant binding of single stranded uracil
25 template. Next, the effects of cleaning up annealed template with this method on retention of annealed oligonucleotides and yield of mutagenized clones was explored.

Analysis of initial libraries

30 Fab phage display libraries were generated starting with 20 µg of uracil template and annealed with a 3-fold molar excess each of 6 oligonucleotides followed by removal of un-annealed excess oligonucleotide prior to the polymerase reaction. Analysis of the polymerase reaction on a TAE/agarose gel revealed a significant
35 reduction in side reaction products relative to a reaction that did not utilize the PCR purification clean-up step. The library size for the mutagenesis reaction utilizing the clean up step was

3.5 x 10⁹ cfu, at least 100-fold larger than the yield of clones obtained without this step. DNA sequence analysis of unselected clones obtained from libraries generated with the clean-up step is shown in Figures 3A-1, 3A-2, 3B-1, 3B-2, 3C-1 and 3C-2. About 15 percent of the clones have all six hypervariable regions replaced; remaining clones were missing various combinations of hypervariable region replacements.

In order to maximize the potential library size, the direct-murine hypervariable region graft onto the template consensus framework was used as a template for the mutagenesis reaction. Therefore, if any combination of hypervariable regions were not replaced during the mutagenesis reaction, at least the wild-type murine hypervariable region would be present, thus leading to a potentially useful clone. Random sequences taken from an initial unselected library designed for humanization of the murine monoclonal antibody Mae11 are shown in Figures 3A-1, 3A-2, 3B-1, 3B-2, 3C-1 and 3C-2. While not all of the hypervariable regions have been replaced, the ones that are mutated reflect a clear murine hypervariable region sequence bias stemming from the soft randomization design of the library.

Affinity of selected clones

Fab phage display libraries based on the murine monoclonal antibodies Mae11 (anti-IgE), D3 (anti-TF) and MHM24 (anti-CD11a), were panned against immobilized IgE, TF and LFA-1, respectively. Significant enrichment was observed by the third round of selection. Random clones were selected from the third and fourth rounds of panning and analyzed by phage ELISA and DNA sequence analysis (Figures 4A-4B). The affinity of the clones generally ranged from 2 to 20 nM with many of the clones falling into the single digit nanomolar range regardless of the library and target. Although this is just an approximation of their true affinity, this places them in the affinity range of the original murine Fab or chimeric Fab affinity (D3 = 14 nM, Mae11 = 3.5 nM and MHM24 = reported as IgG est. 0.1 nM) (Presta et al., *J. Immunol.* 151, 2623-2632 (1993); Werther et al., *J. Immunol. Methods* 157:4986-4995 (1996); and Presta et al., *Thromb. Haemost.* 85:379-389

(2001)).

Sequence analysis of selected clones

Most surprising was the limited and highly concentrated
5 mutations located in the hypervariable regions of the affinity
selected clones (Figures 4A-4B). For the anti-IgE and anti-LFA-1
libraries, mutations were almost exclusively located in H1 and L2,
respectively, while mutations in the anti-TF library were limited
to one of the 3 hypervariable regions in the VL domain. This
10 clustering suggests that these locations are the regions where
solutions to a poor fit of the murine hypervariable regions on the
human framework can be found. Particularly interesting is the fact
that the mutations suggest a consensus solution for improving
affinity.

15 For clones selected for binding to IgE, the changes S34K and
W35L in CDR-H1 of the VH domain appear to be all that is needed to
restore the affinity of the Mae11-based hypervariable region graft
to that of the original murine monoclonal antibody. These residues
are buried and interact with the framework according to the Fab
20 structure of the humanized antibody. They are centrally located
near the surface of the VH domain so that they may also
potentially affect the structural conformations of H2 and H3. By
comparison, humanization by the traditional method involved 12
changes scattered throughout the VL and VH domains (Presta et al.,
25 *J. Immunol.* 151, 2623-2632 (1993)).

Affinity of templates resulting from the direct murine hypervariable region graft

When initially humanizing D3, Mae11 and MHM24, no detectible
30 binding was observed for the direct murine hypervariable region
grafts into the human consensus framework that was used (Presta et
al., *J. Immunol.* 151, 2623-2632 (1993); Werther et al., *J.*
Immunol. Methods 157:4986-4995 (1996); and Presta et al., *Thromb.*
Haemost. 85:379-389 (2001)). Unexpectedly, when the direct murine
35 hypervariable region grafts were made for these antibodies using
the acceptor consensus framework (which differs at 3 positions in
VH: R71A, N73T, and A78L), binding was observed for the D3 and

MHM24 grafts. By phage ELISA the direct grafts had IC50s of 20 and 6 nM respectively. Although most of the selected clones have slightly improved affinities, the presence of un-mutated, directly grafted hypervariable regions (i.e. template background) in these 2 libraries is explained by the initial affinity of the templates.

Importantly, the directly grafted Mae11 template had no measurable affinity for IgE. Thus the few changes made to H1 in these clones demonstrate the potential of restoring antigen binding affinity to directly grafted murine hypervariable regions on a new acceptor without requiring the change of any framework residues. This would suggest that this methodology could be applied to any framework acceptor.

DISCUSSION

Previous efforts to transfer the antigen binding information of murine monoclonal antibodies onto a human acceptor have relied on the introduction of changes within the framework to correct and re-establish proper hypervariable region-antigen interactions. Rather than remodeling the hypervariable region-framework interface by altering framework residues, the examples herein demonstrate that modified hypervariable regions can be selected to correct framework deficiencies while still maintaining antigen interactions.

Phage display of antibody libraries designed to maintain a sequence bias towards the direct hypervariable region-grafted antibody are capable of identifying regions where proper framework-hypervariable region-antigen interactions are disrupted. Although the potential sequence diversity of the library is vastly under represented, potential solutions that can re-establish a beneficial framework-hypervariable region fit are offered. From the Fab sequences that were selected for binding to IgE, it appears that the disruption caused by a single poorly grafted hypervariable region was sufficient to completely disrupt antigen binding (Figures 4A-4B). It is surprising that by changing 2 residues in H1 of the VH domain, a change observed in 11 independent clones, high affinity binding can be restored. These residues reside near and interact with the VH domain framework and

potentially influence the conformations of H1, H2 and H3.

The fact that the initial library was limited in size may explain why observed changes were targeted to a single hypervariable region, since the probability of selecting 2
5 independent changes simultaneously would be quite rare. Although additional improvements could potentially be gained by the generation of subsequent libraries targeting the remaining hypervariable regions, the fact that high affinity clones were selected by this method suggests that most hypervariable region-
10 framework interactions are tolerated and that the identification and alteration of a single offending hypervariable region can lead to restored antigen binding.

Obviously since no changes were made to the framework, the sequence described for final humanized antibody (F(ab)-12, E25)
15 reported by Presta et al. and that of these selected clones is vastly different (Presta et al., *J. Immunol.* 151, 2623-2632 (1993)). In addition, the selected clones in Figures 4A-4B do not incorporate any of the hypervariable region changes made during the traditional humanization process. Thus both humanization
20 methods, despite producing antibodies with similar affinities for antigen result in variants with vastly different sequences. This demonstrates the malleability of the antibody surface and the ability to offer multiple binding solutions to the same problem.

Although the few framework changes that have been
25 incorporated into human therapeutics have not resulted in any known immunological reactions, the absence of these changes would intuitively seem beneficial. Further, the approach taken here demonstrates changes to the framework are not necessary and through the use of antibody phage selection, variants with
30 restored antigen binding can be rapidly identified.

WHAT IS CLAIMED IS:

1. An altered antibody which binds an antigen with a binding affinity (K_d) value of no more than about 5×10^{-7} M, the altered antibody comprising variable heavy (VH) and variable light (VL) acceptor human frameworks and one or more altered hypervariable regions derived from a non-human antibody which binds the antigen, wherein the VH and VL frameworks lack human to non-human amino acid substitutions therein.
- 10 2. The altered antibody of claim 1 wherein the VH and VL frameworks are derived from human consensus frameworks.
3. The altered antibody of claim 2 wherein the VH framework is
15 derived from a VH subgroup III consensus framework.
4. The altered antibody of claim 2 wherein the VL framework is a VL subgroup I consensus framework.
- 20 5. The altered antibody of claim 1 wherein the VH framework comprises an amino acid sequence selected from the group consisting of any one of SEQ ID Nos. 23-41.
6. The altered antibody of claim 1 wherein the VH framework
25 comprises an amino acid sequence selected from the group consisting of any one of SEQ ID Nos. 35-41.
7. The altered antibody of claim 1 wherein the VL framework comprises an amino acid sequence selected from the group
30 consisting of any one of SEQ ID Nos. 42-45.
8. The altered antibody of claim 1 wherein the VL framework comprises the amino acid sequence of SEQ ID NO:42.
- 35 9. The altered antibody of claim 1 comprising one altered hypervariable region and five non-modified hypervariable regions.

10. The altered antibody of claim 1 comprising two altered hypervariable regions and four non-modified hypervariable regions.

11. The altered antibody of claim 1 comprising three altered
5 hypervariable regions and three non-modified hypervariable regions.

12. The altered antibody of claim 1 comprising one, two or three VL altered hypervariable regions.

10

13. The altered antibody of claim 1 comprising H1 and L2 altered hypervariable regions.

14. The altered antibody of claim 1 which binds antigen with a
15 binding affinity no worse than 10 fold the binding affinity of the non-human antibody.

15. The altered antibody of claim 1 wherein the VH comprises FR1-H1-FR2-H2-FR3-H3-FR4, wherein

20 FR1 comprises EVQLVESGGGLVQPGGSLRLSCAAS (SEQ ID NO:1),
FR2 comprises WVRQAPGKGLEWV (SEQ ID NO:2),
FR3 comprises RFTISX1DX2SKNTX3YLQMNSLRAEDTAVYYC (SEQ ID NO:9),
wherein X1 is A or R, X2 is T or N, and X3 is A or L, FR4
comprises WGQGTLVTVSS (SEQ ID NO:4),
25 and H1, H2, and H3 are selected from the group consisting of a non-modified hypervariable region and an altered hypervariable region.

16. The altered antibody of claim 1 wherein the VH comprises FR1-H1-FR2-H2-FR3-H3-FR4, wherein

30 FR1 comprises EVQLVESGGGLVQPGGSLRLSCAAS (SEQ ID NO:1),
FR2 comprises WVRQAPGKGLEWV (SEQ ID NO:2),
FR3 comprises RFTISADTSKNTAYLQMNSLRAEDTAVYYC (SEQ ID NO:10),
RFTISADTSKNTAYLQMNSLRAEDTAVYYCA (SEQ ID NO:11),
35 RFTISADTSKNTAYLQMNSLRAEDTAVYYCAR (SEQ ID NO:12)
RFTISADTSKNTAYLQMNSLRAEDTAVYYCS (SEQ ID NO:13), or
RFTISADTSKNTAYLQMNSLRAEDTAVYYCSR (SEQ ID NO:14),

FR4 comprises WGQGTLLVTVSS (SEQ ID NO:4),
and H1, H2, and H3 are selected from the group consisting of a
non-modified hypervariable region and an altered hypervariable
region.

5

17. The altered antibody of claim 1 wherein the VL comprises FR1-
H1-FR2-H2-FR3-H3-FR4, wherein

FR1 comprises DIQMTQSPSSLSASVGDRVITC (SEQ ID NO:5),

FR2 comprises WYQQKPGKAPKLLIY (SEQ ID NO:6),

10 FR3 comprises GVPSRFSGSGSGTDFTLTISSLQPEDFATYYC (SEQ ID NO:7),

FR4 comprises FGQGTKVEIK (SEQ ID NO:8),

and L1, L2, and L3 are selected from the group consisting of a
non-modified hypervariable region and an altered hypervariable
region.

15

18. The altered antibody of claim 1 which is an antibody fragment
comprising an antigen binding region which binds the antigen.

19. The altered antibody of claim 1 which is an intact antibody.

20

20. The altered antibody of claim 19 which is a human IgG1
antibody.

21. The altered antibody of claim 1 wherein the antigen is
25 selected from the group consisting of tissue factor (TF),
immunoglobulin E (IgE), LFA-1, c-met, and $\beta 7$.

22. Nucleic acid encoding the antibody of claim 1.

30 23. A host cell comprising the nucleic acid of claim 22.

24. A method of making an altered antibody comprising culturing a
host cell comprising the nucleic acid of claim 22 so that the
altered antibody is produced.

35

25. The method of claim 24 further comprising recovering the
antibody from the host cell or host cell culture.

26. A method of making an altered antibody comprising incorporating non-human hypervariable region residues into an acceptor human framework and further comprising introducing one or more amino acid substitutions in one or more hypervariable regions, without modifying the acceptor human framework sequence, and selecting an antibody with a binding affinity (K_d) value of no more than about 5×10^{-7} M.

27. The method of claim 26 comprising incorporating non-human hypervariable region residues into variable heavy (VH) and variable light (VL) acceptor human frameworks and further comprising introducing one or more amino acid substitutions in one or more hypervariable regions, without modifying the VH or VL acceptor human framework sequences.

28. The method of claim 27 wherein the substitutions are made in an antibody displayed on phage or phagemid.

29. The method of claim 28 wherein a library of altered antibodies is created, whereby substitutions in the hypervariable regions are made under conditions which maintain a bias towards the non-human hypervariable region sequence.

30. The method of claim 29 comprising introducing an approximately 10-50 percent mutation rate into nucleic acid encoding each hypervariable region position to be substituted.

31. The method of claim 30 wherein a codon encoding the wild-type hypervariable region amino acid to be mutated is contaminated with a mixture of the other nucleotides.

32. The method of claim 31 wherein a 70-10-10-10 mixture of nucleotides is used.

33. A method of mutating a nucleic acid sequence comprising:

(a) annealing from about two to about 20 oligonucleotides to a single stranded nucleic acid template, wherein the oligonucleotide:template ratio for each oligonucleotide is greater than 1;

- 5 (b) removing excess unannealed oligonucleotides; and
(c) filling in a nucleic acid strand which is complementary to the template.

10 34. The method of claim 33 wherein step (b) comprises exposing a mixture of the template and annealed or unannealed oligonucleotides to a reagent that enables the template, but not oligonucleotides less than 100 base pairs in length, to bind to a silica matrix.

15 35. The method of claim 34 wherein the reagent comprises guanidine hydrochloride.

20 36. The method of claim 33 wherein the nucleic acid sequence encodes an antibody fragment.

37. A method of selecting an altered antibody comprising:
(a) preparing nucleic acid encoding at least the variable heavy (VH) and variable light (VL) domains of an antibody, each comprising an acceptor human framework and hypervariable regions
25 of a non-human antibody;
(b) substituting hypervariable region residues by introducing an approximately 10-50 percent mutation rate into the nucleic acid so as to maintain a bias towards the non-human hypervariable region sequences; and
30 (c) selecting one or more altered antibodies that bind antigen.

38. The method of claim 37 wherein the altered antibodies are displayed on phage or phagemid.

35

VL Domain

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	27a	27b	27c	27d	28	29	30	31	32	33	34	35	36
huK1	D	I	Q	M	T	Q	S	P	S	S	L	S	A	S	V	G	D	R	V	T	I	T	C	CDR-L1										W	Y					
MHM24	D	V	Q	I	T	Q	S	P	S	Y	L	A	A	S	P	G	E	T	I	S	I	N	C	R	A	S	K	T I S K Y L A										W	Y	
Mae11	D	I	V	L	T	Q	S	P	A	S	L	A	V	S	L	G	Q	R	A	T	I	S	C	K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	W	Y
D3	D	I	K	M	T	Q	S	P	S	S	M	S	A	S	L	G	E	S	V	T	I	T	C	K	A	S	R	D I K S Y L S										W	Y	

	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
huK1	Q	Q	K	P	G	K	A	P	K	L	L	I	Y	CDR-L2							G	V	P	S	R	F	S	G	S	G	S	G	T	D	F	T	L	T	I
MHM24	Q	E	K	P	G	K	T	N	K	L	L	I	Y	S G S T L Q S							G	I	P	S	R	F	S	G	S	G	S	G	T	D	F	T	L	T	I
Mae11	Q	Q	K	P	G	Q	P	P	I	L	L	I	Y	A A S Y L G S							E	I	P	A	R	F	S	G	S	G	S	G	T	D	F	T	L	N	I
D3	Q	Q	K	P	W	K	S	P	K	T	L	I	Y	Y A T S L A D							G	V	P	S	R	F	S	G	S	G	S	G	Q	D	Y	S	L	T	I

	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	
huK1	S	S	L	Q	P	E	D	F	A	T	Y	Y	C	CDR-L3										F	G	Q	G	T	K	V	E	I	K	R
MHM24	S	S	L	E	P	E	D	F	A	M	Y	Y	C	Q	Q	H	N	E	Y	P	L	T	F	G	T	G	T	K	L	E	L	K	R	
Mae11	H	P	V	E	E	E	D	A	A	T	F	Y	C	Q	Q	S	H	E	D	P	Y	T	F	G	A	G	T	K	L	E	I	K	R	
D3	S	S	L	E	S	D	D	T	A	T	Y	Y	C	L	Q	H	G	E	S	P	F	T	F	G	S	G	T	K	L	E	L	K	R	

(SEQ ID NOS: 15-18)

FIG. 1A

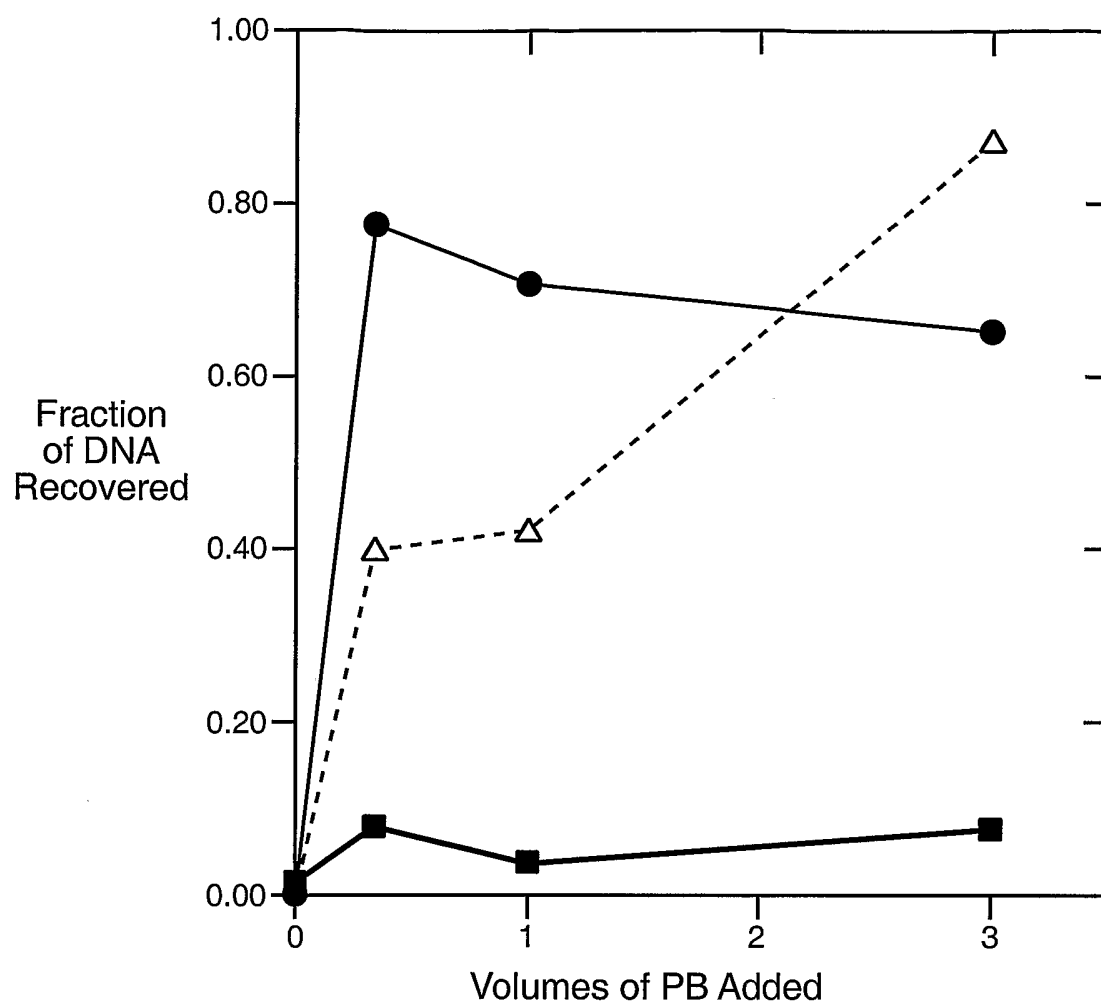
VH Domain

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	35a	36	37	38	39											
Acceptor	E	V	Q	L	V	E	S	G	G	L	V	Q	P	G	G	S	L	R	L	S	C	A	A	S	CDR-H1																									
MHM24	E	V	Q	L	Q	Q	P	G	A	E	L	M	R	P	G	A	S	V	K	L	S	C	K	A	S	G Y S F T G H W M N																								
Mae11	D	V	Q	L	Q	E	S	G	P	G	L	V	K	P	S	Q	S	L	S	L	A	C	S	V	T	G Y S I T S G Y S W N																								
D3	E	V	Q	L	Q	Q	S	G	A	E	L	V	R	P	G	A	L	V	K	L	S	C	K	A	S	G F N I K D Y Y M H																								
40	41	42	43	44	45	46	47	48	49	50	51	52	52a	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79										
Acceptor	A	P	G	K	G	L	E	W	V	CDR-H2																																								
MHM24	R	P	G	Q	G	L	E	W	I	G	M	I	H	P	S	D	S	E	T	R	L	N	Q	K	F	K	D																							
Mae11	F	P	G	N	K	L	E	W	M	G	S	I	T	Y	D	G	S	S	N	Y	N	P	S	L	K	N																								
D3	R	P	E	Q	G	L	E	L	I	G	W	I	D	P	E	N	G	N	T	I	Y	D	P	K	F	Q	D																							
80	81	82	82a	82b	82c	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	100a	100b	100c	100d	101	102	103	104	105	106	107	108	109	110	111	112	113										
Acceptor	L	Q	M	N	S	L	R	A	E	D	T	A	V	Y	Y	C	CDR-H3																																	
MHM24	M	Q	L	S	S	P	T	S	E	D	S	A	V	Y	Y	C	A	R	G	I	Y	F	Y	G	T	T	Y	F	D	Y																				
Mae11	L	K	L	N	S	A	T	A	E	D	T	A	T	Y	Y	C	A	R	G	S	H	Y	F	G	H	W	H	F	A	V																				
D3	L	Q	L	S	S	L	T	S	E	D	T	A	V	Y	Y	C	A	R	D	T	A	A	Y	F D Y																										

(SEQ ID NOS: 19-22)

FIG. 1B

3 / 14

**FIG._2**

VL Domain of Initial D3 Library

CDR-L1

K A S R D I K S Y L S

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

(SEQ ID NOS: 46-65)

CDR-L2

Y A T S L A D

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

(SEQ ID NOS: 66-85)

CDR-L3

L Q H G E S P F T

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

(SEQ ID NOS: 86-105)

FIG._3A-1

VH Domain of Initial D3 Library

CDR-H1
G F N I K D Y Y M H

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

(SEQ ID NOS: 106-125)

CDR-H2
G W I D P E N G N T I Y D P K F Q D

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

(SEQ ID NOS: 126-145)

CDR-H3
R D T A A Y F D Y

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

(SEQ ID NOS: 146-165)

FIG._3A-2

VL Domain of Initial MHM24 Library

CDR-L1	CDR-L2	CDR-L3
R A S K T I S K Y L A	S G S T L Q S	Q Q H N E Y P L T
R A S N T M R R K Y R A	S x R T L Q S	H x H N V S L V T
P A S Y S I K T Y L R	S G S T L E S	Q Q H N E Y P L T
R E G L R F S K D L A	S G S T L E S	Q Q H N E Y P L T
R A S R I M T K T I S	I G C M V P G	Q Q H N E Y P L T
T A C T T L R E x V P	S S C T L Q S	Q Q H K E F P Q T
Y E T K T I T T Y V P	S G G I Q Q S	Q L Q N V Y R L T
G S I K S S R Q N L A	S A S T F Q T	Q x K I D x P T T
R x S S T I W K x L T	C G S T P Q N	Y Q C N D Y Q A S
Y A S I T I S T H P A	S D R P L L S	x H C N E x A Q R
L A S Q P V S R T H G	S G S P L x S	L R Y T P Y P L T
R A S K T I S K Y L A	S G S T L E S	Q Q H N E Y P L T
R A N K I N R I S R S	S G S T L E S	L Q Q K K E S E I
R A S K I I S N N M L	R A I R M H T	K R H N E x L L T
R T N R N I G K F P A	S C W S P Q S	Q Q x S R Y P L A
R A S K T I S I Y R A	S G I T L K S	H K H N E Y P L T
G A S K T I S K Y L A	S G S T L E S	Q Q H N E Y P L T
R A R Q R M S T Y L A	S G S T L E S	Q Q H N E Y P L T
R A R E A F T x H L A	S G S T L E S	Q Q H N E Y P L T
L A R K T L S T D L A	S V D S Q E S	P P T N E Y A L T
R A S K T I S K Y L A	S G S T L E S	Q Q H N E Y P L T
(SEQ ID NOS: 166-186)	(SEQ ID NOS: 187-207)	(SEQ ID NOS: 208-228)

FIG._3B-1

VH Domain of Initial MHM24 Library

CDR-H1

G Y S F T G H W M N

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

(SEQ ID NOS: 229-245)

CDR-H2

G M I H P S D S E T R L N Q K F K D

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

(SEQ ID NOS: 246-262)

CDR-H3

R G I Y F Y G T T Y F D Y

R G I Y F Y G T T Y F D Y
R G I Y F Y G T T Y F D Y
R G I Y S Y E T T F V G Y
R G I Y F Y G T T Y F D Y
R G F H L Y G R T L I D Y
R G I Y F Y G T T Y F D Y
R G I Y F Y G T T Y F D Y
R G I Y F Y G T T Y F D Y
R G N D L Y C T T x F D H
R G I Y F Y G T T Y F D Y
R G I Y F Y G T T Y F D Y
R G I Y F Y G T T Y F D Y
R G I Y F Y G T T Y F N C

K G R Y D N S P T Y C D Y
R G I Y F Y G T T Y F D Y

(SEQ ID NOS: 263-278)

FIG._3B-2

VL Domain of Initial Mae11 Library

CDR-L1												CDR-L2												CDR-L3													
K A S Q S V D Y D G D S Y M N												A A S Y L G S												Q Q S H E D P Y T													
K	A	S	R	R	V	D	F	Y	N	I	S	Y	R	K	A	S	Y	L	G	S	A	V	L	Y	L	V	S	Q	S	H	E	D	P	Y	T		
P	A	S	H	N	V	I	C	D	G	F	I	Y	L	Y	A	V	L	Y	L	V	S	A	R	H	L	G	T	Q	S	H	E	E	A	Y	T		
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	S	A	R	H	L	G	T	S	A	R	H	L	G	T	Q	S	H	E	E	A	Y	T	
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
T	V	S	T	I	L	D	D	V	G	D	N	Y	I	I	M	G	S	Y	R	G	R	A	M	G	S	Y	R	G	R	Q	S	H	E	D	P	Y	T
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	S	G	L	Y	L	G	S	S	G	L	Y	L	G	S	H	L	S	H	G	G	P	N	T
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
I	T	S	x	T	V	V	Y	D	G	Y	S	V	L	L	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
I	D	I	L	S	V	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
D	V	C	Q	R	V	D	K	L	G	D	I	D	S	H	A	S	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
K	S	R	Q	S	V	D	G	K	G	N	Y	I	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T		
K	A	S	Q	S	G	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	
K	A	S	Q	S	V	D	Y	D	G	D	S	Y	M	N	A	A	S	Y	L	G	S	A	A	S	Y	L	G	S	Q	S	H	E	D	P	Y	T	

(SEQ ID NOS: 279-296)

(SEQ ID NOS: 297-314)

(SEQ ID NOS: 315-332)

(SEQ ID NOS: 279-296)

(SEQ ID NOS: 297-314)

(SEQ ID NOS: 315-332)

FIG._3C-1

VH Domain of Initial Mae11 Library

CDR-H1

G Y S I T S G Y S W N

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

(SEQ ID NOS: 333-350)

CDR-H2

G S I T Y D G S S N Y N P S L K N

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

(SEQ ID NOS: 351-368)

CDR-H3

R G S H Y F G H W H F A V

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

(SEQ ID NOS: 369-386)

FIG._3C-2

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Selected Clones from the Mae11 Humanization Library

IC50 (nM)	CDR-H1	Additional Changes		
	A A S <u>G Y S I T S G Y S W N</u> W V R	VL Domain	VH Domain	Siblings
7	A A S G Y S I T S G G Y H L N W V R		E46K	3
4	A A S G Y S I T S G G Y R L N W V R			
7	A A S G Y I I T S G Y K L N W V R			
6	A A S G N S I T S G Y K L N W V R			37
9	A A S G Y S I T S G H K L N W V R			
6	A A S G Y S I T S G Y K L N W V R	P80Q		
6	A A S G Y S I T S G Y K L N W V R		D72Y	12
2	A A S G Y S I T S G Y K L N W V R		S57I	
4	A A S G Y S I T S G Y K L N W V R			
6	A A S G Y S I T S G Y N L N W V R			37
3	A A S G Y S I T S G Y S L H W V R			

(SEQ ID NOS: 387-398)

Selected Clones from the MHM24 Humanization Library

IC50 (nM)	CDR-L2	Additional Changes		
	L L I Y <u>S G S T L Q S</u> G V P S	VL Domain	VH Domain	Siblings
9	L L I Y S G S T L E S G V P S			11
8	L L I Y S G S T L E S G V P S		D101E	
4	L L I Y T G S T L E S G V P S	S26T		
4	L L I Y S G S T L E S G V P S		S55I	2
6	L L I Y S G G T L H R G V P S			
41	L L I Y S G Y S L H R G V P S	K27E, L96V		
11	L L I Y S G R A M Q R G V P S			8
9	L L I Y S G R A L Q S G V P S			
17	L L I Y S G R S L Q S G V P S		S28R	
32	L L I Y N A R S L Q S G V P S			8
8	L L I Y S G S A L Q S G V P S			
6	L L I Y S G S T L Q S G V P S			
11	L L I Y S G S I F Q Y G V P S		Y100dT	8
17	L L I Y S G R T L W P G V P S			
27	L L I Y S G R S L Q R G V P S		L45P	

(SEQ ID NOS: 399-414)

FIG. 4A

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Selected Clones from the D3 Humanization Library

IC50 (nM)	CDR-L1	Additional Changes	
	I T C K A S R D I K S Y L S W Y Q	VL Domain	VH Domain
			Siblings
9	I T C K G S G Y I K H F V S W Y Q		2
19	I T C K G S R D T T S F V S W Y Q		
16	I T C N A S L V I N R W L S W Y Q		
21	I T C K G Q R V L N S W L S W Y Q		
19	I T C K A S R D I K S Y L S W Y Q		5

(SEQ ID NOS: 415-420)

	CDR-L2	
	L I Y Y A T S L A D G V P	
17	L I Y D A I G L A D G V P	
8	L I Y Y A P G L A D G V P	2
4	L I Y Y A P S L A D G V P	
10	L I Y Y A P G P A D G V P	
11	L I Y Y A P R R A R G V P	2
7	L I Y Y E P G L A D G V P	
8	L I Y Y E S G P A D G V P	2
16	L I Y Y A T G E T D G V P	2
10	L I Y Y E T G W A E G V P	
12	L I Y Y E G S G K R G V P	8
11	L I Y Y E T G E P E G V P	
9	L I Y Y E T G P T D G V P	
10	L I Y R G T S L F E G V P	K24E, D28V, Y32F
16	L I Y Y T A G P S D G V P	
21	L I Y Y T T G P V D G V P	
10	L I Y Y V P W T A D G V P	

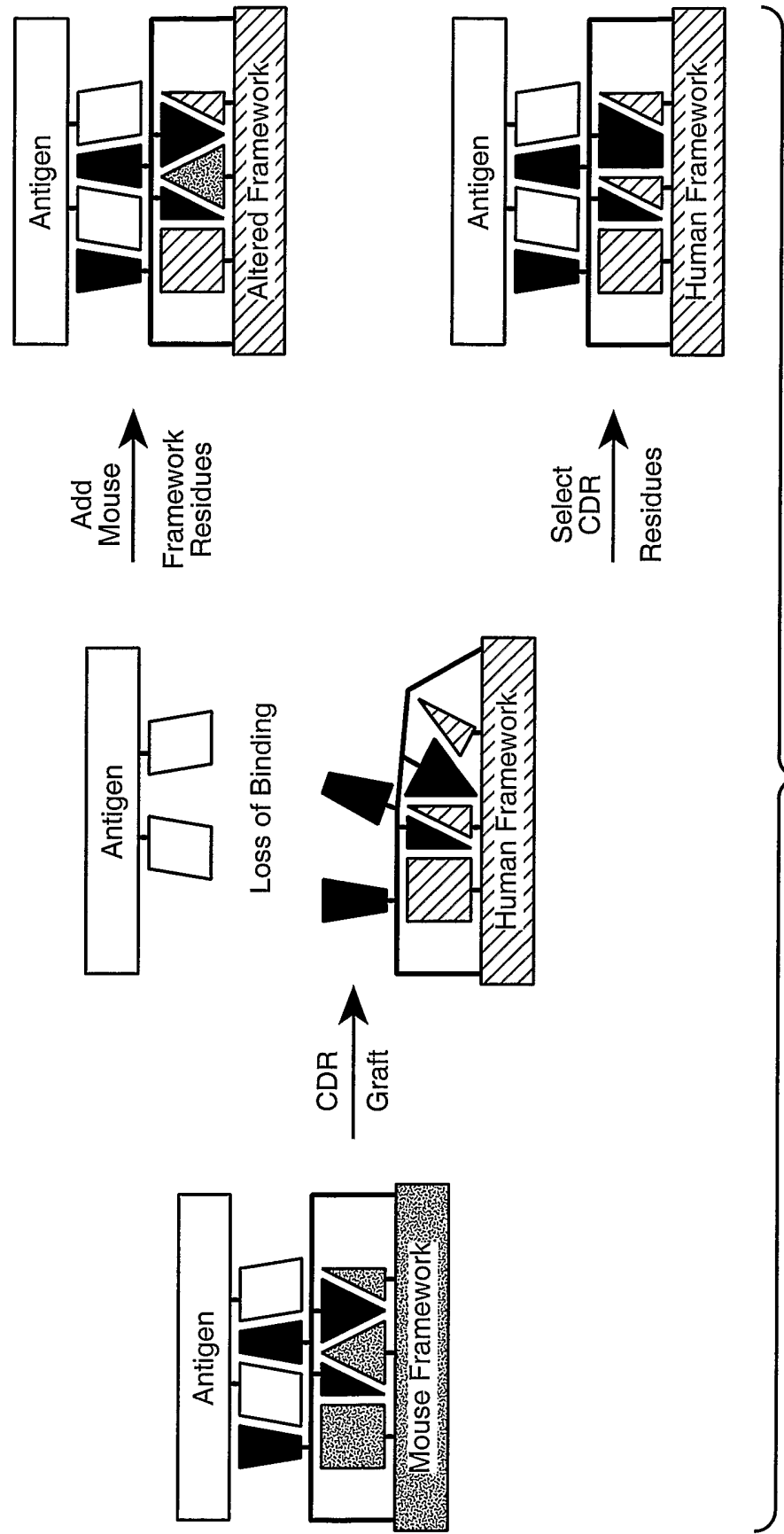
(SEQ ID NOS: 421-437)

	CDR-L3	
	Y Y C L Q H G E S P F T F G Q	
13	Y Y C L Q D G E S P F T F G Q	5
8	Y Y C L Q D G E S P F T F G Q	I58F, N82aI, D95N
15	Y Y C L S D G S S P F T F G Q	

(SEQ ID NOS: 438-441)

FIG. 4B

Ab Humanization Methods



humhv1	A	QVQLVQSGAEVKKPGASVKVSCKASGYTFT	-H1-	WVRQAPGQGLEWMG	-H2-	RVTI
	B	QVQLVQSGAEVKKPGASVKVSCKAS	-H1-	WVRQAPGQGLEWM	-H2-	RVTI
	C	QVQLVQSGAEVKKPGASVKVSCKAS	-H1-	WVRQAPGQGLEWM	-H2-	RVTI
	D	QVQLVQSGAEVKKPGASVKVSCKAS	-H1-	WVRQAPGQGLEWM	-H2-	RVTI
humhv2	A	QVQLQESGPGGLVKPSQTLSTCTVS	-H1-	WIRQPPGKGLEWIG	-H2-	RVTI
	B	QVQLQESGPGGLVKPSQTLSTCTVS	-H1-	WIRQPPGKGLEWI	-H2-	RVTI
	C	QVQLQESGPGGLVKPSQTLSTCTVS	-H1-	WIRQPPGKGLEWI	-H2-	RVTI
	D	QVQLQESGPGGLVKPSQTLSTCTVS	-H1-	WIRQPPGKGLEWI	-H2-	RVTI
humhv3	A	EVQLVESGGGLVQPGGSLRLSCAASGFTFS	-H1-	WVRQAPGKGLEWVS	-H2-	RVTI
	B	EVQLVESGGGLVQPGGSLRLSCAAS	-H1-	WVRQAPGKGLEWV	-H2-	RVTI
	C	EVQLVESGGGLVQPGGSLRLSCAAS	-H1-	WVRQAPGKGLEWV	-H2-	RVTI
	D	EVQLVESGGGLVQPGGSLRLSCAAS	-H1-	WVRQAPGKGLEWV	-H2-	RVTI
Acceptor	A	EVQLVESGGGLVQPGGSLRLSCAASGFNIK	-H1-	WVRQAPGKGLEWVS	-H2-	RVTI
	B	EVQLVESGGGLVQPGGSLRLSCAAS	-H1-	WVRQAPGKGLEWV	-H2-	RVTI
	C	EVQLVESGGGLVQPGGSLRLSCAAS	-H1-	WVRQAPGKGLEWV	-H2-	RVTI
Second Acceptor	A	EVQLVESGGGLVQPGGSLRLSCAASGFNIK	-H1-	WVRQAPGKGLEWVS	-H2-	RVTI
	B	EVQLVESGGGLVQPGGSLRLSCAAS	-H1-	WVRQAPGKGLEWV	-H2-	RVTI
	C	EVQLVESGGGLVQPGGSLRLSCAAS	-H1-	WVRQAPGKGLEWV	-H2-	RVTI
	D	EVQLVESGGGLVQPGGSLRLSCAAS	-H1-	WVRQAPGKGLEWV	-H2-	RVTI
humkv1		DIQMTQSPSSLSASVGDRTITC	-L1-	WYQQKPGKAPKLLIY	-L2-	GVPSRFSGSGS
humkv2		DIVMTQSPSLPVTGPESISC	-L1-	WYLQKPGQSPQLLIY	-L2-	GVPDFSGSGS
humkv3		EIVLTQSPGTISLSPGERATLSC	-L1-	WYQQKPGQAPRLLIY	-L2-	GIPDRFSGSGS
humkv4		DIVMTQSPDSLAVSLGERATINC	-L1-	WYQQKPGQPPKLLIY	-L2-	GVPDFSGSGS

FIG. 6A

humhv1	A	TADTSTSTAYMELSSLSRSED	TAVYYCAR	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 23
	B	TADTSTSTAYMELSSLSRSED	TAVYYCAR	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 24
	C	TADTSTSTAYMELSSLSRSED	TAVYYCA	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 25
	D	TADTSTSTAYMELSSLSRSED	TAVYYC	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 26
humhv2	A	SVDTSKNQFSLKLSSVTAAD	TAVYYCAR	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 27
	B	SVDTSKNQFSLKLSSVTAAD	TAVYYCAR	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 28
	C	SVDTSKNQFSLKLSSVTAAD	TAVYYCA	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 29
	D	SVDTSKNQFSLKLSSVTAAD	TAVYYC	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 30
humhv3	A	SRDNSKNTLYLQMNSLRAED	TAVYYCAR	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 31
	B	SRDNSKNTLYLQMNSLRAED	TAVYYCAR	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 32
	C	SRDNSKNTLYLQMNSLRAED	TAVYYCA	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 33
	D	SRDNSKNTLYLQMNSLRAED	TAVYYC	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 34
Acceptor	A	SADTSKNTAYLQMNSLRAED	TAVYYC ^{SR}	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 35
	B	SADTSKNTAYLQMNSLRAED	TAVYYC ^{SR}	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 36
	C	SADTSKNTAYLQMNSLRAED	TAVYYC ^S	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 37
Second Acceptor	A	SADTSKNTAYLQMNSLRAED	TAVYYCAR	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 38
	B	SADTSKNTAYLQMNSLRAED	TAVYYCAR	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 39
	C	SADTSKNTAYLQMNSLRAED	TAVYYCA	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 40
	D	SADTSKNTAYLQMNSLRAED	TAVYYC	-H3-	WGQGT	TLVTVSS	SEQ ID NO.: 41
humkv1		GTDFTLTISSLPEDFA	TYYC	-L3-	FGQGT	KVEIK	SEQ ID NO.: 42
humkv2		GTDFTLTKISRVEAEDV	GVYC	-L3-	FGQGT	KVEIK	SEQ ID NO.: 43
humkv3		GTDFTLTISRLEPEDFA	VYYC	-L3-	FGQGT	KVEIK	SEQ ID NO.: 44
humkv4		GTDFTLTISSLQAEDVA	VYYC	-L3-	FGQGT	KVEIK	SEQ ID NO.: 45

FIG._6B