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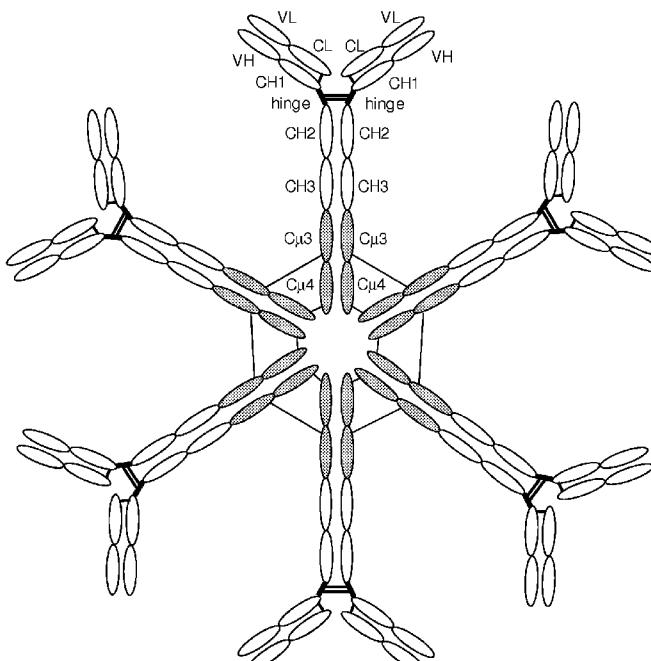
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(54) Title: HYBRID CONSTANT REGIONS



(57) Abstract: The invention provides hybrid constant regions and antibodies or fusion proteins incorporating the same. The hybrid constant regions include at least CH2 and CH3 regions of an IgG or IgA constant region and Cμ3 and Cμ4 regions of a Cμ constant region. The hybrids retain properties of both component constant regions. The hybrids retain the ability of a Cμ constant region to form multivalent complexes, e.g., pentameric or hexameric structures. IgG hybrids also retain IgG properties including pH-dependent FcRn binding, which is associated with a relatively long *in vivo* half-life, and specific binding to protein G, which facilitates purification. Depending on the isotype and subtype, the nature of the antigen and presence of additional IgG CH1 and hinge domains, IgG hybrids may also retain properties of specific binding to protein A, and effector functions ADCC, CDC and opsonization. IgA hybrids retain the property of IgA of binding to an Fc-alpha receptor CD89.



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## HYBRID CONSTANT REGIONS

### CROSS-REFERENCE TO RELATED APPLICATION

**[0001]** The present application is a non-provisional of USSN 61/539,416; filed September 26, 2011.

### BACKGROUND

**[0002]** Antibodies are glycoproteins produced by B cells that play an essential role in the immune system (Schroeder et al., *J. Allergy Clin. Immunol.* 125:S41-S52, 2010). Five classes of antibodies, namely IgM, IgD, IgG, IgA and IgE, are produced in mammals. In humans, four subclasses of IgG (IgG1, IgG2, IgG3 and IgG4) and two subclasses of IgA (IgA1 and IgA2) antibodies are produced. Each antibody is composed of two identical light chains and two identical heavy chains in the monomeric form. These four chains are connected to one another by a combination of covalent and non-covalent bonds, and form a Y-shaped molecule. There are two types of light chains, kappa and lambda, in mammals. Several different types of heavy chains exist that define the class of an antibody. In humans, the  $\mu$  heavy chain is incorporated in IgM, the delta heavy chain in IgD, the gamma-1 heavy chain in IgG1, the gamma-2 heavy chain in IgG2, the gamma-3 heavy chain in IgG3, the gamma-4 heavy chain in IgG4, the alpha-1 heavy chain in IgA1, the alpha-2 heavy chain in IgA2, and the epsilon heavy chain in IgE. A monomeric form of these antibodies has two antigen binding sites, and thus is divalent for antigen binding. Although IgG, IgD and IgE are exclusively produced as a monomer, IgM is produced as a hexamer, and thus is dodecavalent for antigen binding, in the absence of J chains, and forms a decavalent pentamer when J chains are present (Gilmour et al., *Trans. Med.* 18:167-174, 2008). IgA forms a tetravalent dimer with a J chain, whereas IgA is a monomer when J chains are absent, although spontaneous formation of dimeric IgA without J chains has been reported (Johansen et al., *Scand. J. Immunol.* 52:240-248, 2000).

**[0003]** The U.S. Food and Drug Administration had approved twenty-eight monoclonal antibodies as human therapeutics by the end of 2010. All of these therapeutic antibodies are IgG antibodies or derivatives thereof. Besides specific antigen binding, IgG antibodies elicit various biological functions mediated by the Fc region (Schroeder et al. *supra*; Desjarlais et al., *Exp. Cell Res.* 317:1278-1285, 2011). In humans, cell-bound IgG1 and IgG3 antibodies

mediate antibody-dependent cell-mediated cytotoxicity (ADCC) by binding of the Fc region to Fc $\gamma$  receptor type III (CD16) expressed on NK cells (Hulett et al., *Adv. Immunol.* 57:1-127, 1994). Likewise, cell-bound IgG1 and IgG3 antibodies can efficiently trigger complement-dependent cytotoxicity (CDC) by the interaction of the Fc region with complement components (Bindon et al., *J. Exp. Med.* 168:127-142, 1988).

**[0004]** The Fc region of all four subclasses of human IgG antibodies binds to the neonatal Fc receptor (FcRn), which is a heterodimer composed of a transmembrane  $\alpha$  chain and  $\beta$ 2-microglobulin, in a pH-dependent manner, resulting in rescuing IgG antibodies internalized by pinocytosis from catabolic degradation in lysosomes and allowing their recycling to the circulation (Ghetie et al., *Annu. Rev. Immunol.* 18:739-766, 2000). IgG antibodies therefore exhibit slow clearance from the circulation which results in a long serum half-life, typically 23 days, in humans (Kindt et al., Chapter 4, *Kuby Immunology*, Sixth Edition, W. H. Freeman & Co., 2006). In addition, the Fc region of IgG antibodies bind to Protein A (except for IgG3) and Protein G, so that purification of IgG antibodies by Protein A or Protein G affinity chromatography is possible (Andrew et al., Unit 2.7, Chapter III, *Current Protocols in Immunology*, John Wiley & Sons, Inc. 1997).

**[0005]** Dimerization of specific molecules on the cell surface can often trigger one or more biological responses. Binding of monoclonal IgG antibodies to PSMA (prostate-specific membrane antigen) proteins on the cell surface increases the rate of PSMA internalization (Liu et al., *Cancer Res.* 58:4055-4060, 1998). Internalization and down-regulation of a type I transmembrane protein MUC1 is triggered by binding to a mouse IgG1 antibody (Hisatsune et al., *Biochem. Biophys. Res. Commun.* 388:677-382, 2009). Monoclonal antibodies against c-Met dimerize c-Met proteins on the cell surface and initiate intracellular signals resulting in cell proliferation (Prat et al., *J. Cell Sci.* 111:237-247, 1998). Likewise, a monoclonal anti-EPO receptor antibody can function as an agonist for cell growth by homodimerization of EPO receptors on the surface (Schneider et al., *Blood* 89:473-482, 1997). Antibody-mediated dimerization of Death Receptor 5 (DR5), a member of tumor necrosis factor receptor (TNFR) super-family, on the cell surface, however, does not always trigger signal transduction, while multimerization of DR5 proteins by a mixture of mouse monoclonal anti-DR5 IgG antibody and goat anti-mouse IgG polyclonal antibody, for example, induces signal transduction in the cytoplasm and triggers apoptosis (Griffith et al., *J. Immunol.* 162:2597-2605, 1999).

**[0006]** IgM antibodies exist as pentamers with J chains and hexamers without J chains (Gilmour et al., *supra*). In contrast to IgG antibodies, which are only capable of dimerizing

antigens, IgM can multimerize cell surface proteins due to its decavalent or dodecavalent antigen binding capability. Monoclonal IgM antibodies with specificity for Fas, a member of the TNFR superfamily (Cosman, Stem Cells 12:440-455, 1994), can efficiently induce apoptosis of Fas-expressing cells due to multimerization of Fas proteins on the surface (Yonehara et al., J. Exp. Med. 169:1747-1756, 1989) while anti-Fas IgG antibodies do not unless they are cross-linked (Matsuno et al., J. Rheumatol. 29:1609-1614, 2002). Compared to IgG, IgM exhibits a much shorter circulation half-life, typically 5 days in humans, because of its inability to bind to FcRn (Kindt et al., *supra*). IgM antibodies are also unable to mediate ADCC due to the lack of binding to CD16. In addition, the lack of binding to Protein A and Protein G by IgM makes it impossible to purify IgM by Protein A and Protein G affinity chromatography, respectively (Gautam et al., Biotechnol. Adv. E-publication, July 2011).

**[0007]** A variety of structural formats have been utilized in an attempt to generate novel forms of multivalent antibodies. Recent advances in the engineering of multivalent antibodies are summarized in a review paper of Cuesta et al. (Trends Biotech., 28:355-362, 2010). Preferred multivalent IgG antibodies are able to multimerize antigens efficiently on the cell surface. It is also important that the properties mediated by the Fc region of gamma heavy chains, such as ADCC, CDC, opsonization, pH-dependent FcRn binding, and the ability to bind to Protein A and Protein G, are maintained in such multivalent IgG antibodies.

**[0008]** To generate a multivalent IgG antibody, Caron et al. (J. Exp. Med., 176:1191-1195, 1992) introduced a serine-to-cysteine substitution at the fourth position from the carboxyl terminal of human gamma-1 heavy chain in the humanized anti-CD33 IgG1/kappa antibody, HuG1-M195. Such modified HuG1-M195, termed Hd-IgG, was purified and subjected to Ellman's Reagent (Pierce Chemical Co., Rockford, IL) for crosslinking and then blocking of excess sulphhydryl sites. Monomeric HuG1-M195 was eliminated from Hd-IgG by phenyl Sepharose column chromatography. The resultant Hd-IgG showed a dramatic improvement in the ability to internalize CD33 molecules and was more potent than HuG1-M195 at ADCC and CDC.

**[0009]** Miller et al. (J. Immunol., 170:4854-4861, 2003) constructed a tetravalent IgG antibody by duplicating the VH-CH1 region in the heavy chain of the humanized anti-HER2 IgG1 monoclonal antibody, hu4D5. The modified gamma heavy chain was composed of, from the N-terminus to the C-terminus, the VH, CH1, VH, CH1, hinge, CH2 and CH3 regions. One light chain bound to each of the four VH-CH1 regions in the modified IgG, forming a tetravalent hu4D5 antibody (TA-HER2). TA-HER2 was internalized more rapidly

than the parental divalent hu4D5 on HER2-expressing cells. Miller et al. (supra) also constructed a tetravalent anti-DR5 IgG antibody, termed TA-DR5, in the same heavy chain format as in TA-HER2. TA-DR5 triggered apoptosis at ~100-fold lower concentration than the parental divalent anti-DR5 IgG monoclonal antibody.

**[0010]** Rossi et al. (Cancer Res., 68:8384-8392, 2008) reported the construction of a hexavalent anti-CD20 IgG antibody, designated Hex-hA20, using the Dock-and-Lock method. To generate Hex-hA20, which was composed of six Fab and two Fc regions, two components were constructed and separately produced in mammalian cells. First, the anchoring domain of the A-kinase anchoring proteins (AD) was genetically fused to the carboxyl terminus of the heavy chain in the humanized anti-CD20 IgG1 antibody, hA20. This construct was designated CH3-AD2-IgG-hA20. Second, the docking domain of the cyclic AMP-dependent protein kinase (DDD) was genetically fused to the carboxyl terminus of the Fab fragment of h20. This construct was designated CH1-DDD2-Fab-hA20. CH3-AD2-IgG-hA20 and CH1-DDD2-Fab-hA20 were purified by Protein A and Protein L affinity chromatography, respectively. Hex-hA20 was obtained by mixing purified CH3-AD2-IgG-hA20 and CH1-DDD2-Fab-hA20 under redox conditions followed by purification with Protein A. Hex-h20 inhibited proliferation of CD20-expressing B lymphoma cells lines without the need for a cross-linking antibody. Hex-h20 retained the ADCC activity of hA20, but lost the CDC activity.

**[0011]** Yoo et al. (J. Biol. Chem., 47:33771-33777, 1999) constructed variant human anti-DNS IgG2 antibodies in which part of the gamma-2 heavy chain was replaced with the corresponding part of the human alpha-1 heavy chain. In the construct termed  $\gamma\gamma\gamma$ -atp, the 18-amino acid polypeptide present in the C-terminus of the human alpha-1 heavy chain, termed atp (also called alpha tailpiece), was attached at the C-terminus of the human gamma-2 heavy chain. The  $\gamma\gamma\gamma$ -atp construct was further modified to generate the following three variant IgG2 antibodies. In  $\alpha\gamma\gamma$ -atp, the CH1 region of the gamma-2 heavy chain was replaced with the counterpart of the human alpha-1 heavy chain. In  $\alpha\alpha\gamma$ -atp, the CH1, hinge and CH2 regions were replaced with the counterparts of the human alpha-1 heavy chain. In  $\gamma\alpha\gamma$ -atp, the hinge and CH2 regions were replaced with the counterparts of the human alpha-1 heavy chain. These constructs were stably expressed in the mouse myeloma cell line Sp2/0 producing J chains. Each of purified  $\gamma\gamma\gamma$ -atp,  $\alpha\gamma\gamma$ -atp,  $\alpha\alpha\gamma$ -atp and  $\gamma\alpha\gamma$ -atp antibodies was a mixture of monomers, dimers, trimers, tetramers, pentamers and hexamers. The combined percentage of hexamers and pentamers in the mixture was 20% for  $\gamma\gamma\gamma$ -atp, 25% for  $\alpha\gamma\gamma$ -atp, 45% for  $\alpha\alpha\gamma$ -atp, and 32% for  $\gamma\alpha\gamma$ -atp.

**[0012]** Sorensen et al. (J. Immunol. 156:2858-2865, 1996) generated multivalent antibodies based on a human monoclonal anti-NIP (3-nitro-4-hydroxy-5-iodophenylacetic acid) IgG3 antibody variant in which the first, second and third hinge region are deleted. The gamma-3 heavy chain gene of this variant IgG3 antibody was modified in two locations. First, the 18-amino acid polypeptide present in the C-terminus of the human  $\mu$  heavy chain, termed  $\mu$ tp (also called mu tailpiece), was attached at the C-terminus of the heavy chain. Second, a leucine residue at position 309 in the CH2 region was changed to a cysteine residue. Such modified monoclonal IgG3 antibody, called IgGL309C $\mu$ tp, was expressed in the mouse myeloma cell line J558L producing J chains, and purified using an NIP-Sepharose column. The secretion level was reported to be poorer for IgGL309C $\mu$ tp than for the parental IgG3 antibody, and a large fraction of IgGL309C $\mu$ tp was retained intracellularly. The size analysis showed that pentamers and hexamers constituted 81% of purified IgGL309C $\mu$ tp.

**[0013]** Sorensen et al. (Int. Immunol., 12:19-27, 2000) also modified the same human anti-NIP IgG3 antibody variant as described above by substituting the CH2 and CH3 regions of the gamma-3 heavy chain with the CH3 and CH4 regions, including  $\mu$ tp, of the human  $\mu$  heavy chain. The heavy chain of such modified IgG3/IgM hybrid molecules, termed IgG-C $\mu$ 3-C $\mu$ 4, is composed of, from the N-terminus, the anti-NIP VH region, the CH1 and fourth hinge region of the human gamma-3 heavy chain, and the CH3 and CH4 regions, including  $\mu$ tp, of the human  $\mu$  heavy chain. IgG-C $\mu$ 3-C $\mu$ 4 was expressed in J558L cells producing J chains and purified using an NIP-Sepharose column. Hexamers and pentamers constituted 14.0% and 66.7%, respectively, in purified IgG-C $\mu$ 3-C $\mu$ 4. Since IgG-C $\mu$ 3-C $\mu$ 4 does not have the CH2 and CH3 regions of the human gamma-3 heavy chain, it will lack Fc $\gamma$ -mediated properties such as ADCC, pH-dependent FcRn binding, and the ability to bind to Protein A and Protein G.

#### SUMMARY OF THE CLAIMED INVENTION

**[0014]** The invention provides an antibody or fusion protein comprising an immunoglobulin heavy chain constant region, comprising in order from N- to C-terminus CH2 and CH3 regions, each of which is of IgG or IgA isotype, and C $\mu$ 3 and C $\mu$ 4 regions. Optionally, the immunoglobulin heavy chain further comprises a hinge region N-terminal to the CH2 region. Optionally, the immunoglobulin heavy chain further comprises a CH1 region N-terminal to the hinge region.

**[0015]** Optionally, the antibody or fusion protein is an antibody, wherein the heavy chain constant region is fused to a heavy chain variable region and the antibody further comprises a light chain comprising a light chain variable region and constant region. Optionally, the antibody is a component of a multi-specific antibody comprising a plurality of antibodies with different heavy chain variable regions, and optionally different light chain variable regions; the plurality of antibodies being complexed in the multi-specific antibody via the C $\mu$ 3 and C $\mu$ 4 regions.

**[0016]** Optionally, in an antibody or fusion protein mentioned above, the CH1 region, and hinge region, if present, and the CH2 and CH3 regions in an antibody or fusion protein of the invention are IgG1 regions. Optionally, the CH1 region and hinge region, if present, and the CH2 and CH3 regions in an antibody or fusion protein are IgG2 regions. Optionally, the CH1 region and hinge region, if present, and the CH2 and CH3 regions in an antibody or fusion protein are IgG3 regions. Optionally, the CH1 region and hinge region, if present, and the CH2 and CH3 regions in an antibody or fusion protein are IgG4 regions. Optionally, the CH1 region if present, and the CH2 and CH3 regions are IgA regions. Optionally, the CH1 region, and the hinge region, if present, and the CH2 and CH3 regions are human CH1, hinge, CH2 and CH3 regions and the C $\mu$ 3 and C $\mu$ 4 regions are human C $\mu$ 3 and C $\mu$ 4 regions.

**[0017]** Optionally, the antibody or fusion protein is a single-chain antibody comprising a single-chain Fv linked to the heavy chain constant region. Optionally, the single-chain antibody is a component of a multi-specific antibody comprising a plurality of single-chain antibodies, wherein the scFvs of the plurality have different VH regions, and the plurality of single-chain antibodies are complexed in the multi-specific antibody via the C $\mu$ 3 and C $\mu$ 4 regions. Optionally, the scFvs have the same VL region.

**[0018]** Optionally, an antibody or fusion protein is in the form of a multimer comprising at least five or six copies of a unit comprising two of the heavy chains and two of the light chains, the copies being complexed in the multimer via the C $\mu$ 3 and C $\mu$ 4 regions.

**[0019]** Optionally, in an antibody or fusion protein as mentioned above, the CH1 region, if present, the hinge region and CH2 and CH3 regions are IgG and the antibody or fusion protein shows pH-dependent FcRn binding, specifically binds protein G, specifically binds protein A, exhibits ADCC, CDC and/or opsonization.

**[0020]** Optionally, in an antibody or fusion protein as mentioned above, the CH1 region, if present, and the hinge region, and CH2 and CH3 are human IgG1 regions and the antibody shows pH-dependent FcRn binding, specifically binds protein G, and specifically

binds protein A. Optionally, such an antibody or fusion protein exhibits ADCC, CDC and opsonization.

**[0021]** Optionally, in an antibody or fusion protein as mentioned above, the CH1 region if present, and the hinge, CH2 and CH3 regions are human IgG2 or IgG4 regions and the antibody or fusion protein shows pH-dependent FcRn binding, specifically binds protein G and specifically binds protein A.

**[0022]** Optionally, in an antibody or fusion protein as mentioned above, the CH1 region if present, and the hinge region, and CH2 and CH3 regions are human IgG3 and the antibody shows pH-dependent FcRn binding, and specifically binds protein G. Optionally, the antibody or fusion protein of claim 20 that exhibits ADCC, CDC and opsonization.

**[0023]** Optionally, in an antibody or fusion protein as mentioned above, the CH1 region if present, and the CH2 and CH3 regions are human IgA and the antibody binds an Fc alpha receptor.

**[0024]** Optionally, an antibody or fusion protein as mentioned above is a fusion protein comprising the immunoglobulin heavy chain linked to a heterologous polypeptide. Optionally, the heterologous protein is linked to the hinge of the constant region via a flexible linker, such as Gly-Gly-Ala-Ala. Optionally, the heterologous polypeptide is a receptor extracellular domain or a polypeptide that specifically binds to a receptor extracellular domain. Optionally, the fusion protein is a component of a multi-specific complex comprising a plurality of fusion protein, the fusion proteins including different heterologous polypeptides.

**[0025]** Optionally, an antibody or fusion protein as mentioned above is a multispecific complex comprising an antibody and a fusion protein complexed via the C $\mu$ 3 and C $\mu$ 4 regions.

**[0026]** Optionally, an antibody or fusion protein as mentioned above is a humanized, chimeric, veneered or human antibody.

**[0027]** Optionally, an antibody or fusion protein as mentioned above specifically binds the extracellular domain of a receptor.

**[0028]** Optionally, an antibody or fusion protein as mentioned above specifically binds to CD79a, CD30, or DR5.

**[0029]** Optionally, an antibody or fusion protein as mentioned above is a fusion protein comprising an extracellular domain of a TNF-alpha receptor, LFA-3 or an IL-1 receptor, or is a fusion protein comprising a TRAIL protein.

**[0030]** Optionally, an antibody or fusion protein as mentioned above is conjugated to a toxic moiety, optionally, a cytotoxic moiety.

**[0031]** The invention further provides a pharmaceutical composition comprising an antibody or fusion protein as mentioned above.

**[0032]** The invention further provides a method of treating cancer comprising administering to a patient having or at risk of cancer an effective regime of an antibody or fusion protein as mentioned above.

**[0033]** The invention further provides a method of treating an immunological disorder comprising administering to a patient having or at risk of the disorder an effective regime of an antibody or fusion protein as mentioned above.

**[0034]** The invention further provides a method of producing a multi-specific complex of antibodies and/or fusion proteins, comprising a. transfecting a cell with a vector or vectors encoding a plurality of antibodies and/or fusion proteins as defined by claim 1, the antibodies and/or fusion proteins having different specificities; wherein the antibodies and/or fusion proteins are expressed and assembled into a multispecific complex via the C $\mu$ 3 and C $\mu$ 4 regions; and b. isolating the multi-specific complex from the cell culture. Optionally, each of the plurality of antibodies or fusion proteins is encoded by a different vector.

**[0035]** The invention further provides an antibody or fusion protein comprising a hybrid constant region comprising an N-terminal IgG constant region segment and a C-terminal IgM constant region segment; wherein the antibody exhibits pH dependent FcRn binding, specifically binds protein G, and multimerizes to form at least a pentamer or hexamer via the IgM constant region.

#### BRIEF DESCRIPTION OF THE DRAWING

**[0036]** Figure 1: Schematic structure of antibody expression vectors.

**[0037]** Figure 2: Schematic structure of recombinant antibodies in the monomeric form.

**[0038]** Figures 3A-E: Elution pattern of anti-CD79a IgG1 antibodies from a Superose 6 gel filtration column.

**[0039]** Figure 4: Induction of apoptosis of Ramos cells by multivalent anti-CD79a IgG1 antibodies.

**[0040]** Figure 5: pH-dependent binding of multivalent IgG1 antibodies to FcRn.

**[0041]** Figures 6A-I: Binding of multivalent IgG1 antibodies to CD16.

[0042] Figures 7A-D: Elution pattern of anti-CD30 IgG1 antibodies from a Superose 6 gel filtration column.

[0043] Figure 8: Cytostasis of Karpas 299 cells by multivalent anti-CD30 IgG1 antibodies.

[0044] Figure 9: Elution pattern of multivalent anti-CD30 IgG1 antibody expressed in HEK293 cells from a Superose 6 gel filtration column.

[0045] Figures 10A-D: Elution pattern of anti-DR5 IgG1 antibodies from a Superose 6 gel filtration column.

[0046] Figure 11: Apoptosis of Jurkat cells induced by multivalent anti-DR5 IgG1 antibodies.

[0047] Figures 12A-C: Elution pattern of the multivalent anti-CD79a IgG4 antibody from a Superose 6 gel filtration column.

[0048] Figures 13A-E: Elution pattern of anti-CD79a IgG3 antibodies from a Superose 6 gel filtration column.

[0049] Figure 14: pH-dependent binding of multivalent IgG3 antibodies to FcRn.

[0050] Figures 15A-G: Binding of multivalent IgG3 antibodies to CD16.

[0051] Figures 16 A, B, C: Sequences of gamma-1 (SEQ ID NOs:15-18), gamma-2 (SEQ ID NOs:19-22), gamma-3 (SEQ ID NOs:23-26), gamma-4 (SEQ ID NOs:27-30), alpha-1 (SEQ ID NOs:31-33), alpha-2 (SEQ ID NOs:34-36), mu heavy chain constant regions (SEQ ID NOs:51-54), and a J chain (SEQ ID NO:55). The 18 amino acid mu tailpiece is underlined in the Cmu sequence. The first 22 amino acids shown of the J chain are a cleaved signal peptide.

[0052] Figure 17: An exemplary antibody with a hybrid constant region in hexameric conformation. Interchain disulfide bonds are shown by linear lines. Each monomeric unit has two binding sites, each formed from a heavy chain and a light chain variable region. Six monomeric units are bonded to one another via disulfide bonding between the C $\mu$ 3 and C $\mu$ 4 regions of different monomeric units. The antibody shown including the valency and disulfide bonding pattern are but one embodiment of the invention provided for illustration.

[0053] Figure 18: Survival data of Ramos-bearing CB17 SCID mice treated with HuYON007-MVIgG1 or HuYON007-IgG1.

## DEFINITIONS

**[0054]** Antibodies or fusion proteins are typically provided in isolated form. This means that an antibody or fusion protein is typically at least 50% w/w pure of interfering proteins and other contaminants arising from its production or purification but does not exclude the possibility that the monoclonal antibody is combined with an excess of pharmaceutical acceptable carrier(s) or other vehicle intended to facilitate its use. Sometimes antibodies or fusion proteins are at least 60, 70, 80, 90, 95 or 99% w/w pure of interfering proteins and contaminants from production or purification. Often an antibody or fusion protein is the predominant macromolecular species remaining after its purification.

**[0055]** Specific binding of an antibody or fusion protein to its target antigen means an affinity of at least  $10^6$ ,  $10^7$ ,  $10^8$ ,  $10^9$ , or  $10^{10}$  M<sup>-1</sup>. Specific binding is detectably higher in magnitude and distinguishable from non-specific binding occurring to at least one unrelated target. Specific binding can be the result of formation of bonds between particular functional groups or particular spatial fit (e.g., lock and key type) whereas nonspecific binding is usually the result of van der Waals forces. Specific binding does not however necessarily imply that an antibody or fusion protein binds one and only one target.

**[0056]** A basic antibody structural unit is a tetramer of subunits. Each tetramer includes two identical pairs of polypeptide chains, each pair having one "light" (about 25 kDa) and one "heavy" chain (about 50-70 kDa). The amino-terminal portion of each chain includes a variable region of about 100 to 110 or more amino acids primarily responsible for antigen recognition. This variable region is initially expressed linked to a cleavable signal peptide. The variable region without the signal peptide is sometimes referred to as a mature variable region. Thus, for example, a light chain mature variable region means a light chain variable region without the light chain signal peptide. However, reference to a variable region does not mean that a signal sequence is necessarily present; and in fact signal sequences are cleaved once the antibodies or fusion proteins of the invention have been expressed and secreted. A pair of heavy and light chain variable regions defines a binding region of an antibody. The carboxy-terminal portion of the light and heavy chains respectively defines light and heavy chain constant regions. The heavy chain constant region is primarily responsible for effector function. In IgG antibodies, the heavy chain constant region is divided into CH1, hinge, CH2, and CH3 regions. In IgA, the heavy constant region is divided into CH1, CH2 and CH3. The CH1 region binds to the light chain constant region by disulfide and noncovalent bonding. The hinge region provides flexibility between the

binding and effector regions of an antibody and also provides sites for intermolecular disulfide bonding between the two heavy chain constant regions in a tetramer subunit. The CH2 and CH3 regions are the primary site of effector functions and FcRn binding. In IgM antibodies, the  $\mu$  heavy chain constant region (C $\mu$ ) is subdivided into four regions C $\mu$ 1, C $\mu$ 2, C $\mu$ 3 and C $\mu$ 4. The C $\mu$ 3 and C $\mu$ 4 regions, sometimes in combination with one or more J chains, provide a multimerization function in natural IgM antibodies and antibodies or fusion proteins of the present invention. The mu tailpiece is a 18 amino-acid-long polypeptide located at the C-terminus of a IgM heavy chain constant region. IgM multimerizes to form a pentameric structure in the presence of J chains and a hexameric structure in their absence.

**[0057]** Light chains are classified as either kappa or lambda. Heavy chains are classified as gamma, mu, alpha, delta, or epsilon, and define the antibody's isotype as IgG, IgM, IgA, IgD and IgE, respectively. Within light and heavy chains, the variable and constant regions are joined by a "J" segment of about 12 or more amino acids, with the heavy chain also including a "D" segment of about 10 or more amino acids. (*See generally, Fundamental Immunology* (Paul, W., ed., 2nd ed. Raven Press, N.Y., 1989), Ch. 7) (incorporated by reference in its entirety for all purposes).

**[0058]** The mature variable regions of each light/heavy chain pair form the antibody binding site. Thus, an intact antibody has two binding sites, i.e., is divalent. In natural antibodies, the binding sites are the same. However, bispecific antibodies can be made in which the two binding sites are different (see, e.g., Songsivilai and Lachmann, *Clin. Exp. Immunol.*, 79:315-321 (1990); Kostelny et al., *J. Immunol.*, 148:1547-53 (1992)). The variable regions all exhibit the same general structure of relatively conserved framework regions (FR) joined by three hypervariable regions, also called complementarity determining regions or CDRs. The CDRs from the two chains of each pair are aligned by the framework regions, enabling binding to a specific epitope. From N-terminal to C-terminal, both light and heavy chains comprise the domains FR1, CDR1, FR2, CDR2, FR3, CDR3 and FR4. The assignment of amino acids to each domain is in accordance with the definitions of Kabat, *Sequences of Proteins of Immunological Interest* (National Institutes of Health, Bethesda, MD, 1987 and 1991), or Chothia & Lesk, *J. Mol. Biol.* 196:901-917 (1987); Chothia et al., *Nature* 342:878-883 (1989). Kabat also provides a widely used numbering convention (Kabat numbering) in which corresponding residues between different heavy chain variable regions or between different light chain variable regions are assigned the same number. Although Kabat numbering can be used for antibody constant regions, the EU index is more commonly used, as is the case in this application.

**[0059]** A multimerization unit is the monomeric unit of an antibody or fusion protein incorporating a hybrid constant region of the invention subject to multimerization by its IgM portion. A multimerization unit can itself be mono or divalent. In a mono-specific divalent antibody unit, the two heavy chains and two light chains are the same. In a bispecific divalent antibody unit, there are two different heavy and light chain pairings with different binding specificities. An antibody unit can also be monovalent containing a single heavy and light chain combination, as is the case with single-chain antibodies in which the heavy and light variable regions pair intramolecularly. A fusion protein unit can be monomeric, homodimeric containing two copies of a fusion protein or heterodimeric, containing two different fusion proteins.

**[0060]** Multimerization means the association of at least two multimerization units and more typically five or six such units via the C $\mu$  portion of a hybrid constant region. Multimerization of antibodies or fusion proteins with a hybrid constant region may sometimes form higher or lower order structures than the pentameric or hexameric structure of normal IgM. Such is sometimes indicated by characterizing a complex formed by multimerization as having at least about five or six units.

**[0061]** Valency refers to the number of binding regions or in other words, maximum number of molecules of a target antigen that can be bound by an antibody or fusion protein. A normal homodimeric IgG antibody has a valency of two. A normal IgM antibody has a valency of 10 or 12 depending on whether a pentameric or hexameric structure is formed (i.e., five or six IgM units, each being a tetramer with two binding sites). Antibodies or fusion proteins of the present invention in which the monomeric unit is bivalent, can have valencies of 10 or 12, whereas antibodies or fusion proteins in which the monomeric unit is monovalent can have valencies of 5 or 6. The valencies may vary from these values in that antibody or fusion proteins with hybrid constant regions may sometimes form higher or lower order structures than the pentameric or hexameric structure of normal IgM. These valencies are theoretical maxima. In practice, the numbers of copies of an antigen bound may be less than the theoretical maximum due to steric constraints.

**[0062]** An antibody or fusion protein of the invention is mono-specific if all of its antigen (or ligand) binding regions have the same specificity. An antibody or fusion protein is multispecific if its antigen binding regions include at least two different specificities. The number of different specificities in a multispecific antibody or fusion protein can range from 2 up to the maximum valency of the antibody or fusion protein (e.g., 10 or 12). In a

population of antibodies or fusion proteins produced by the same cell culture, the number of different specificities can vary among different members of the population.

**[0063]** The term “antibody” includes any form of antibody with at least one binding region including monovalent fragments, divalent tetrameric units of two heavy chains and light chains, and higher order complexes, particularly pentamers and hexamers of monovalent or divalent units. An antibody can be mono-specific in which case all binding regions have the same specificity or multi-specific in which the binding sites have at least two specificities. Antibody fragments typically include a heavy chain variable region and hybrid heavy chain constant region and may also include a light chain variable region. For example, an antibody fragment can include from N-terminal to C-terminal a light chain variable region, a peptide spacer, a heavy chain variable region and a hybrid heavy chain constant region of the invention. Another fragment includes a heavy chain variable region (the binding region) and a hybrid heavy chain constant region and no light chain (i.e., a Dab or nanobody). Likewise, a fusion protein includes a monomeric or dimeric fusion protein unit, or higher order complexes, particularly pentamers and hexamers.

**[0064]** The term “epitope” refers to a site on an antigen to which an antibody or fusion protein binds. An epitope can be formed from contiguous amino acids or noncontiguous amino acids juxtaposed by tertiary folding of one or more proteins. Epitopes formed from contiguous amino acids (also known as linear epitopes) are typically retained on exposure to denaturing solvents whereas epitopes formed by tertiary folding (also known as conformational epitopes) are typically lost on treatment with denaturing solvents. Some antibodies bind to an end-specific epitope, meaning an antibody binds preferentially to a polypeptide with a free end relative to the same polypeptide fused to another polypeptide resulting in loss of the free end. An epitope typically includes at least 3, and more usually, at least 5 or 8-10 amino acids in a unique spatial conformation. Methods of determining spatial conformation of epitopes include, for example, x-ray crystallography and 2-dimensional nuclear magnetic resonance. See, e.g., Epitope Mapping Protocols, in Methods in Molecular Biology, Vol. 66, Glenn E. Morris, Ed. (1996).

**[0065]** The term “antigen” or “target antigen” indicates a target molecule bound by an antibody or fusion protein. An antigen may be a protein of any length (natural, synthetic or recombinantly expressed), a nucleic acid or carbohydrate among other molecules. Antigens include receptors, ligands, counter receptors, and coat proteins.

**[0066]** A heterologous polypeptide in a fusion protein is a polypeptide not naturally linked to an immunoglobulin constant region. Such a polypeptide can be a full-length protein

or any fragment thereof of sufficient length to retain specific binding to the antigen bound by the full-length protein. For example, a heterologous polypeptide can be a receptor extracellular domain or ligand thereto.

**[0067]** Antibodies that recognize the same or overlapping epitopes can be identified in a simple immunoassay showing the ability of one antibody to compete with the binding of another antibody to a target antigen. The epitope of an antibody can also be defined X-ray crystallography of the antibody bound to its antigen to identify contact residues. Alternatively, two antibodies have the same epitope if all amino acid mutations in the antigen that reduce or eliminate binding of one antibody reduce or eliminate binding of the other. Two antibodies have overlapping epitopes if some amino acid mutations that reduce or eliminate binding of one antibody reduce or eliminate binding of the other.

**[0068]** Competition between antibodies is determined by an assay in which an antibody under test inhibits specific binding of a reference antibody to a common antigen (see, e.g., Junghans et al., *Cancer Res.* 50:1495, 1990). A test antibody competes with a reference antibody if an excess of a test antibody (e.g., at least 2x, 5x, 10x, 20x or 100x) inhibits binding of the reference antibody by at least 50% but preferably 75%, 90% or 99% as measured in a competitive binding assay. Antibodies identified by competition assay (competing antibodies) include antibodies binding to the same epitope as the reference antibody and antibodies binding to an adjacent epitope sufficiently proximal to the epitope bound by the reference antibody for steric hindrance to occur.

**[0069]** The term “patient” includes human and other mammalian subjects that receive either prophylactic or therapeutic treatment.

**[0070]** For purposes of classifying amino acids substitutions as conservative or nonconservative, amino acids are grouped as follows: Group I (hydrophobic side chains): met, ala, val, leu, ile; Group II (neutral hydrophilic side chains): cys, ser, thr; Group III (acidic side chains): asp, glu; Group IV (basic side chains): asn, gln, his, lys, arg; Group V (residues influencing chain orientation): gly, pro; and Group VI (aromatic side chains): trp, tyr, phe. Conservative substitutions involve substitutions between amino acids in the same class. Non-conservative substitutions constitute exchanging a member of one of these classes for a member of another.

**[0071]** Percentage sequence identities are determined with antibody sequences maximally aligned by the Kabat numbering convention for a variable region or EU numbering for a constant region. After alignment, if a subject antibody region (e.g., the entire mature variable region of a heavy or light chain) is being compared with the same

region of a reference antibody, the percentage sequence identity between the subject and reference antibody regions is the number of positions occupied by the same amino acid in both the subject and reference antibody region divided by the total number of aligned positions of the two regions, with gaps not counted, multiplied by 100 to convert to percentage.

**[0072]** Compositions or methods "comprising" one or more recited elements may include other elements not specifically recited. For example, a composition that comprises antibody may contain the antibody alone or in combination with other ingredients.

**[0073]** The term "antibody-dependent cellular cytotoxicity", or ADCC, is a mechanism for inducing cell death that depends upon the interaction of antibody-coated target cells (i.e., cells with bound antibody) with immune cells possessing lytic activity (also referred to as effector cells). Such effector cells include natural killer cells, monocytes/macrophages and neutrophils. ADCC is triggered by interactions between the Fc region of an antibody bound to a cell and Fc $\gamma$  receptors, particularly Fc $\gamma$ RI and Fc $\gamma$ RIII, on immune effector cells such as neutrophils, macrophages and natural killer cells. The target cell is eliminated by phagocytosis or lysis, depending on the type of mediating effector cell. Death of the antibody-coated target cell occurs as a result of effector cell activity.

**[0074]** The term opsonization also known as "antibody-dependent cellular phagocytosis", or ADCP, refers to the process by which antibody-coated cells are internalized, either in whole or in part, by phagocytic immune cells (e.g., macrophages, neutrophils and dendritic cells) that bind to an immunoglobulin Fc region.

**[0075]** The term "complement-dependent cytotoxicity" or CDC refers to a mechanism for inducing cell death in which an Fc effector domain(s) of a target-bound antibody activates a series of enzymatic reactions culminating in the formation of holes in the target cell membrane. Typically, antigen-antibody complexes such as those on antibody-coated target cells bind and activate complement component C1q which in turn activates the complement cascade leading to target cell death. Activation of complement may also result in deposition of complement components on the target cell surface that facilitate ADCC by binding complement receptors (e.g., CR3) on leukocytes.

**[0076]** pH-dependent binding of an antibody to an FcRn receptor means that an antibody binds more strongly to such a receptor at pH 6.0 than at pH 7.5. Binding of FcRn at a low pH in endosomes after internalization by pinocytosis rescues IgG antibodies from catabolic degradation in lysosomes. Rescued IgG antibodies are then released from FcRn at a neutral pH and recycled to the circulation. Such pH-dependent FcRn binding is the basis of

the molecular mechanism for a long serum half-life of IgG antibodies (and antibodies and fusion proteins incorporating hybrid constant regions of the invention) (Ghetie et al., Annu. Rev. Immunol. 18:739-766, 2000). For example, human IgG antibodies bind to human neonatal Fc receptors (FcRn) at pH 6.0 while they bind only weakly to FcRn at pH 7.5. The FcRn binding site in IgG antibodies lies at the junction of the CH2 and CH3 domains. Because a  $\mu$  heavy chain does not bind to FcRn at pH 6.0 or 7.5, natural IgM cannot take advantage of the FcRn-mediated pathway to rescue antibodies from degradation in lysosomes and therefore in general have shorter half-lives than natural IgG antibodies.

**[0077]** A humanized antibody is a genetically engineered antibody in which the CDRs from a non-human “donor” antibody are grafted into human “acceptor” antibody sequences (see, e.g., Queen, US 5,530,101 and 5,585,089; Winter, US 5,225,539, Carter, US 6,407,213, Adair, US 5,859,205 6,881,557, Foote, US 6,881,557). The acceptor antibody sequences can be, for example, a mature human antibody sequence, a composite of such sequences, a consensus sequence of human antibody sequences, or a germline region sequence. Thus, a humanized antibody is an antibody having some or all CDRs entirely or substantially from a donor antibody and variable region framework sequences and constant regions, if present, entirely or substantially from human antibody sequences. Similarly a humanized heavy chain has at least one, two and usually all three CDRs entirely or substantially from a donor antibody heavy chain, and a heavy chain variable region framework sequence and heavy chain constant region, if present, substantially from human heavy chain variable region framework and constant region sequences. Similarly a humanized light chain has at least one, two and usually all three CDRs entirely or substantially from a donor antibody light chain, and a light chain variable region framework sequence and light chain constant region, if present, substantially from human light chain variable region framework and constant region sequences. Other than nanobodies and dAbs, a humanized antibody comprises a humanized heavy chain and a humanized light chain. A CDR in a humanized antibody is substantially from a corresponding CDR in a non-human antibody when at least 85%, 90%, 95% or 100% of corresponding residues (as defined by Kabat) are identical between the respective CDRs. The variable region framework sequences of an antibody chain or the constant region of an antibody chain are substantially from a human variable region framework sequence or human constant region respectively when at least 85, 90, 95 or 100% of corresponding residues defined by Kabat are identical.

**[0078]** Although humanized antibodies often incorporate all six CDRs (preferably as defined by Kabat) from a mouse antibody, they can also be made with less than all CDRs

(e.g., at least 3, 4, or 5 CDRs from a mouse antibody) (e.g., Pascalis *et al.*, *J. Immunol.* 169:3076, 2002; Vajdos *et al.*, *Journal of Molecular Biology*, 320: 415-428, 2002; Iwahashi *et al.*, *Mol. Immunol.* 36:1079-1091, 1999; Tamura *et al.*, *Journal of Immunology*, 164:1432-1441, 2000).

**[0079]** A chimeric antibody is an antibody in which the mature variable regions of light and heavy chains of a non-human antibody (e.g., a mouse) are combined with human light and heavy chain constant regions. Such antibodies substantially or entirely retain the binding specificity of the mouse antibody, and are about two-thirds human sequence.

**[0080]** A veneered antibody is a type of humanized antibody that retains some and usually all of the CDRs and some of the non-human variable region framework residues of a non-human antibody but replaces other variable region framework residues that may contribute to B- or T-cell epitopes, for example exposed residues (Padlan, *Mol. Immunol.* 28:489, 1991) with residues from the corresponding positions of a human antibody sequence. The result is an antibody in which the CDRs are entirely or substantially from a non-human antibody and the variable region frameworks of the non-human antibody are made more human-like by the substitutions.

**[0081]** A human antibody can be isolated from a human, or otherwise result from expression of human immunoglobulin genes (e.g., in a transgenic mouse, in vitro or by phage display). Methods for producing human antibodies include the trioma method of Oestberg *et al.*, *Hybridoma* 2:361-367 (1983); Oestberg, U.S. Patent No. 4,634,664; and Engleman *et al.*, US Patent 4,634,666, use of transgenic mice including human immunoglobulin genes (see, e.g., Lonberg *et al.*, WO93/12227 (1993); US 5,877,397, US 5,874,299, US 5,814,318, US 5,789,650, US 5,770,429, US 5,661,016, US 5,633,425, US 5,625,126, US 5,569,825, US 5,545,806, *Nature* 148, 1547-1553 (1994), *Nature Biotechnology* 14, 826 (1996), Kucherlapati, WO 91/10741 (1991) and phage display methods (see, e.g. Dower *et al.*, WO 91/17271 and McCafferty *et al.*, WO 92/01047, US 5,877,218, US 5,871,907, US 5,858,657, US 5,837,242, US 5,733,743 and US 5,565,332).

**[0082]** Protein A is a 40-60 kDa surface protein originally found in the cell wall of the bacterium *Staphylococcus aureus*. Protein A specifically binds with high affinity to human IgG1, IgG2 and IgG4 as well as mouse IgG2a and IgG2b. It does not bind to human IgG3 or IgA, or IgM. Protein A is used for affinity purification of antibodies.

**[0083]** Protein G is a 65-kDa (G148 protein G) and a 58 kDa (C40 protein G) Streptococcal cell surface protein. It contains a serum albumin binding domain not needed

for IgG binding, which is often deleted. Protein G specifically binds to all of the human IgG isotypes but not IgA or IgM. Protein G is also useful for antibody purification.

## DETAILED DESCRIPTION

### I. General

**[0084]** The invention provides hybrid constant regions and antibodies or fusion proteins incorporating the same. The hybrid constant regions include at least CH2 and CH3 regions of an IgG or IgA constant region and C $\mu$ 3 and C $\mu$ 4 regions of a C $\mu$  constant region. The hybrids retain properties of both component constant regions. The hybrids retain the ability of a C $\mu$  constant region to form multivalent complexes, e.g., pentameric or hexameric structures (as shown in Fig. 17). IgG hybrids also retain IgG properties including pH-dependent FcRn binding, which is associated with a relatively long in vivo half-life, and specifically binding to protein G, which facilitates purification. Depending on the isotype and subtype, the nature of the antigen and presence of additional IgG CH1 and hinge domains, IgG hybrids may also retain properties of specific binding to protein A, and effector functions ADCC, CDC and opsonization. IgA hybrids retain the property of IgA of binding to an Fc-alpha receptor CD89 (Swiss Prot P24071) in humans.

**[0085]** The combination of IgG effector functions, relatively long half-life and ease of purification with IgM's ability to multimerize results in antibodies or fusion protein with novel combinations of properties. For example, some such antibodies or fusion protein can effectively multimerize receptors or bound ligands on the cell surface while maintaining, or even enhancing, Fc $\gamma$ -mediated properties such as ADCC, CDC, opsonization, pH-dependent FcRn binding, and the ability to bind to Protein A and Protein G relative to antibodies having an IgG isotype. The combination of properties from different isotypes offers the possibility of greater potency than conventional IgG, IgM or IgA antibodies for treatment of cancer and other diseases.

**[0086]** IgM's ability to multimerize also provides a format for making multi-specific complexes of antibodies and fusion proteins in which units with different specificities are held together by bonding between IgM constant regions.

**[0087]** The above advantages can be achieved without in vitro manipulations other than those involved in making nucleic acid constructs for expression of the hybrid antibodies or fusion proteins.

## II. Components of Hybrid Constant Regions

**[0088]** The hybrid constant regions include an IgG or IgA portion and a C $\mu$  portion. The IgG or IgA portion includes at least IgG or IgA CH2 and CH3 regions. The CH2 and CH3 regions are responsible at least in part for FcRn binding, protein A and G binding, ADCC, CDC and opsonization. The IgG portion also preferably includes a hinge region and/or a CH1 region. The hinge region provides flexibility between the binding region and effector region of an antibody or fusion protein and contributes to efficient effector functions, such as ADCC, opsonization and CDC. The hinge region is also the site of disulfide bonds that link a pair of IgG heavy chains together. The CH1 region bonds with a light chain constant region and is generally included in formats in which a light chain with light chain constant region is present but can be omitted in fusion proteins or single-chain antibody formats in which no light chain constant region is present. IgA does not have a hinge region according to the Kabat delineation of regions. However, the residues in CH1 and CH2 flanking the border between these regions in IgA provide flexibility effectively serving the role of a hinge region. CH1 is preferably included in IgA fusions including an antibody light chain constant region and is preferably omitted otherwise.

**[0089]** The C $\mu$  portion includes C $\mu$ 3 and C $\mu$ 4 of a C $\mu$  constant region. The C $\mu$  portion is responsible for multimerizing multiple monovalent or divalent binding units into a multivalent complex. Although understanding of mechanism is not required for practice of the invention, it is believed that multimerization of hybrid antibodies or fusion proteins occurs in similar fashion as in natural IgM antibodies through interchain disulfide bonding between the C $\mu$ 3 regions of different monomers and between the mu tailpieces of different monomers. Some multimers of IgM also contain one or more J chains bound to the mu tailpiece. In the presence of one or more J chains IgM can form a pentameric structure and in the absence of J chains can form a hexameric structure. Hexameric IgM has been reported to have stronger CDC than pentameric. Although antibodies and fusion proteins of the invention are believed to form pentameric or hexameric complexes as for IgM, other multiplicities greater or smaller may form as well or instead of pentameric and hexameric forms.

**[0090]** The components mentioned are above are arranged from N-terminus to C-terminus in the order: IgG or IgA CH1 region (if present), IgG hinge region (if present), IgG or IgA CH2 region, IgG or IgA CH3 region, C $\mu$ 3 region, and C $\mu$ 4 region.

**[0091]** Usually, all of the IgG or IgA regions are of the same isotype and subtype. That is, all IgG regions are either from IgG1, IgG2, IgG3 or IgG4, and all IgA regions are either from IgA1 or IgA2.

**[0092]** Preferably, the IgG or IgA regions are human IgG or IgA regions. Likewise, the C $\mu$ 3 and C $\mu$ 4 regions are preferably human. Exemplary sequences for human IgG1, IgG2, IgG3, IgG4, IgA1, IgA2, IgM heavy chain constant regions with delineation into components (CH1, hinge, CH2, CH3, C $\mu$ 1, C $\mu$ 2, C $\mu$ 3 and C $\mu$ 4 and a J-chain are shown in Figs. 16 A, B, C. However, regions from other species including nonhuman primates, camelids, cartilaginous fish, mice or rats can also be used.

**[0093]** Reference to a human IgG, IgA or IgM region (i.e., CH1, hinge, CH2, CH3, C $\mu$ 3 and C $\mu$ 4) or J-chain refers to the exemplified sequences or allotypes or isoallotypes thereof or other variant sequence having at least 90, 95, 98 or 99% sequence identity with an exemplified sequence and/or differing from the exemplified sequence by up to 1, 2, 3, 4, 5, 10 or 15 amino acid deletions, substitution or internal insertions in the case of CH1, CH2, CH3, C $\mu$ 3 and C $\mu$ 4 and a J-chain and 1, 2 or 3 deletions, substitutions or internal substitutions for IgG1, 2 or 4 hinge regions and up to 1, 2, 3, 4, 5, or 6 deletions for IgG3 hinge. Substitutions, if present, are preferably conservative. Human constant regions show allotypic variation and isoallotypic variation between different individuals, that is, the constant regions can differ in different individuals at one or more polymorphic positions. Isoallotypes differ from allotypes in that sera recognizing an isoallotype bind to a non-polymorphic region of a one or more other isotypes. Reference to a human constant region includes a constant region with any natural allotype (including isoallotypes) or any permutation of residues occupying polymorphic positions in natural allotypes. Sequences of non-human constant regions are provided by e.g., the Swiss-Prot or Genbank databases. Reference to a non-human constant region likewise includes allotypic or isoallotypic variants, and permutations of the same, or other variants sequences differing from natural sequences. The scope of variations is defined by sequence identity and/or number of substitutions with respect to natural sequences of non-human constant regions in analogous fashion to the above description of variants with respect to human constant regions. The Eu numbering convention is used in defining corresponding positions among isotypes or different species, or defining mutated positions.

**[0094]** One or several amino acids at the amino or carboxy terminus of the light and/or heavy chain, such as a C-terminal lysine of the heavy chain, may be missing or derivatized in a proportion or all of the molecules. Substitutions can be made in the constant regions to

reduce or increase effector function such as complement-mediated cytotoxicity or ADCC (see, e.g., Winter et al., US Patent No. 5,624,821; Tso et al., US Patent No. 5,834,597; and Lazar et al., Proc. Natl. Acad. Sci. USA 103:4005, 2006), or to prolong half-life in humans (see, e.g., Hinton et al., J. Biol. Chem. 279:6213, 2004). Exemplary substitutions include a Gln at position 250 and/or a Leu at position 428 (EU numbering) for increasing the half-life of an antibody. Substitution any of positions 234, 235, 236 and/or 237 reduce affinity for Fc $\gamma$  receptors, particularly Fc $\gamma$ RI receptor (see, e.g., US 6,624,821). Optionally, positions 234, 236 and/or 237 in human IgG2 are substituted with alanine and position 235 with glutamine. (See, e.g., US 5,624,821.)

**[0095]** If a hinge region is used, part of the hinge can be replaced by a synthetic linker molecule. Such is often the case in fusion proteins in which a binding region of the fusion protein is joined to CH2 and CH3 IgG or IgA constant regions via a hinge region in which, for example, up to 10 N-terminal residues are replaced by a synthetic flexible linker. Gly-Gly-Ala-Ala, Gly-Gly-Gly-Ser, Leu-Ala-Ala-Ala-Ala and multimers thereof are examples of such a linker. The hinge region can also be replaced in its entirety by a synthetic linker or omitted without replacement.

**[0096]** With the possible exception of a synthetic linker replacing part or all of a hinge region and one or a few amino acid substitutions to enhance or suppress effector functions or FcRn binding as discussed further below, and the attachment of a binding region at the N-terminus, it is preferred that hybrid constant regions contain no sequences other than the CH1, hinge, CH2, CH3, C $\mu$ 3 and C $\mu$ 4 regions mentioned above. Nevertheless, other sequences, such as for example, a hexa-histidine tag, can be added but are not necessary.

### III. Properties of Fusions

**[0097]** The properties of an antibody or fusion protein incorporating a hybrid heavy chain constant region as described above depend in part on the isotype, and subtype of the CH1, hinge (if present), CH2 and CH3 regions, whether the CH1 and/or hinge regions are present, and the nature of the antigen bound by the antibody or fusion protein.

**[0098]** Antibodies and fusion proteins incorporating the hybrid constant regions retain at least the ability of C $\mu$ 3 and C $\mu$ 4 to multimerize a monovalent or divalent unit to higher valency and at least one property of IgG or IgA antibodies. When CH1, hinge (if present), CH2 and CH3 are of IgG origin, the antibodies retain at least the IgG-like properties of binding protein G and pH-dependent FcRn binding, as well as capacity to specifically bind to a target antigen.

**[0099]** Selection of isotype or subtype depends on the desired properties. As with non-hybrid antibodies, IgG1 or IgG3 is selected if strong effector functions are desired (as is often the case against cancer cells, pathogens) and IgG2 or IgG4 is selected if weaker or no CDC, ADCC and opsonization are required (as may be the case if the mechanism is inhibition of a receptor-ligand interaction).

**[00100]** When the CH1 and hinge regions (if present), CH2 and CH3 regions are human IgG1, then an antibody or fusion protein incorporating a hybrid constant region has pH-dependent FcRn binding, specific binding to protein A, and protein G, and may have effector functions, such as ADCC, CDC, opsonization depending on the antigen bound. Such effector functions are usually present if the antigen bound is a surface receptor (e.g., on a cell or virus). If the antigen is normally in soluble form, effector functions are not usually expressed against the soluble antigen but can be demonstrated by expressing the antigen in bound form (e.g., on a cell surface).

**[00101]** When the CH1 and hinge regions (if present), CH2 and CH3 regions are human IgG2, IgG4, then an antibody or fusion protein incorporating a hybrid heavy chain constant region shows at least pH-dependent FcRn binding and specific binding to protein A and protein G. Human IgG2 and IgG4 isotypes generally lack CDC. IgG4 has some ADCC and opsonization against bound antigens but less than human IgG1 or IgG3.

**[00102]** When the CH1 and hinge regions (if present), CH2 and CH3 regions are human IgG3, then an antibody or fusion protein incorporating a hybrid heavy chain constant region shows at least pH-dependent FcRn binding, and specific binding to protein G. Such an antibody or fusion protein may also show effector functions, such as ADCC, CDC, opsonization depending on whether the antigen bound is a surface antigen or soluble, as is the case for IgG1.

**[00103]** In antibodies or fusion proteins with hybrid constant regions in which CDC, ADCC or opsonization is present, the level of CDC, ADCC, or opsonization is sometimes the same as (within experimental error) or sometimes greater than that of an otherwise comparable antibody or fusion protein with a conventional IgG constant region.

#### IV. Antibody and Fusion Protein Formats

**[00104]** Hybrid constant regions can be incorporated into mono-specific antibodies, fusion proteins, and multi-specific complexes. For expression of a mono-specific antibody, a hybrid heavy chain constant region can be linked to a heavy chain variable region and expressed with a light chain comprising a variable region and constant region. The heavy and

light chain bind to one another via the CH1 region of the heavy chain and light chain constant region to a form a heterodimer. Two heterodimers then pair by association of hinge, CH2 and CH3 regions of the IgG or IgA portion of the heavy chain to form a tetramer unit, as is the case for a conventional antibody. Tetramer units can further multimerize by association of the C $\mu$  portion of the heavy chain constant regions of the units. The heavy chain constant regions can associate by disulfide bonding between C $\mu$ 3 regions of different chains and/or by disulfide bonding between the mu tailpieces of different chains.

**[00105]** For a mono-specific single-chain antibody, heavy and light chain variable regions are expressed as part of the same chain typically separated by a peptide spacer (see, e.g., US 5,260,203, US 5869203, US 6,291,159). The length of the peptide spacer determines whether heavy and light chain variable regions associate intramolecularly forming a unit containing one light chain variable region intramolecularly paired to one heavy chain variable region or intermolecularly forming a tetrameric unit of two light chain variable regions and two heavy chain variable regions, each light chain variable region intermolecularly bonded to a heavy chain variable region. In either case, the units can multimerize via the C $\mu$  portion of a hybrid constant region linked to the heavy chain variable region. Multimerization via disulfide bonding of the C $\mu$  portion can result in complexes containing at least about five or six units.

**[00106]** The hybrid constant regions can be used with any type of engineered antibody including chimeric, humanized, veneered or human antibodies. The antibody can be a monoclonal antibody or a genetically engineered polyclonal antibody preparation (see US 6,986,986).

**[00107]** For fusion protein proteins, a hybrid constant region is expressed linked to a heterologous polypeptide. The heterologous polypeptide provides a binding region at the N-terminus of the constant region and is sometimes referred to simply as a binding region. The IgG or IgA CH1 region is not typically included in the constant region for fusion proteins. The IgG hinge region may or may not be included. In some fusion proteins, part or all of the hinge region is replaced by a synthetic linker peptide conferring flexibility between the binding portion of a fusion protein and the hybrid constant region.

**[00108]** The binding region of a fusion protein can be any of the types of binding portion used in other fusion proteins produced to date (among others). Examples of binding regions are extracellular domains of cellular receptors or their ligands or counter-receptors (e.g., TNF-alpha receptor, LFA3 or IL-1 receptor or Trail).

**[00109]** Both antibody and fusion proteins can be expressed in a multi-specific format, that is, as a complex containing antibody or fusion protein units within different target specificities. Individual specificities associate via multimerization of the C $\mu$  portion of the constant region. The number of different specificities within a complex can be, for example, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12. Combinations of units of different specificities can occur at two levels. In the first level, a divalent multimerization unit can contain two binding specificities as in a bispecific antibody or a heterodimeric fusion protein. In the second level of combination, multimerization units of different specificities can combine with one another via C $\mu$ -mediated multimerization. Such multimerization generates complexes of at least about five or six units.

**[00110]** When the two levels of combining specificities are aggregated, the present methods allow combining at least about 10 (pentamers) or 12 (hexamers) specificities in the same complex. Although in many applications, this number of specificities may be more than needed, the present methods offer an advantage in applications where fewer specificities are needed (e.g., only 2). Because of the second level at which specificities are combined, it becomes statistically much more likely that any complex formed includes at least one unit of each desired specificity. By contrast, when expressing a bispecific antibody by conventional methods, formation of multi-specific units may compete with formation of mono-specific units leading to a heterogeneous population of antibodies, some of which are bispecific but of which a substantial number are mono-specific.

**[00111]** In multi-specific formats of antibodies, the units typically contain different heavy chain variable regions. The light chain variable regions can also be different. However, it is also possible to select (e.g., using phage display) antibodies of different binding specificities having the same light chain variable region. Such antibodies can be combined in a multispecific format in which the units have different heavy chain variable regions but the same light chain variable region.

**[00112]** A multi-specific antibody or fusion protein can include binding specificities for an antigen on a target (e.g., a cancer cell or pathogen) and for an antigen on an effector cell (e.g., CD3 on a T-cell). Such a multi-specific complex forms a bridge between the target cell and effector cell and promotes cytotoxic or opsonization activity of the effector cell. A multi-specific antibody or fusion protein can additionally or alternatively include binding specificities for two different antigens on the same target (e.g., a cancer cell or pathogen). Such an antibody or fusion protein can have greater selective toxicity to the target cell than an antibody or fusion protein with specificity for a single antigen. Other multi-specific

antibodies or fusion proteins include binding regions for both a receptor and its ligand or counter-receptor. Such antibodies or fusion proteins can exert greater inhibition than antibodies or fusion proteins binding receptor or ligand/counterreceptor alone. Any of these specificities and others can be combined in the same multi-specific complex.

#### V. Genetic Engineering and Expression

**[00113]** Antibodies or fusion proteins including a hybrid heavy chain constant chain are produced by recombinant expression. A hybrid constant region is achieved by fusing a DNA segment encoding the IgG or IgA portion in-frame with a DNA segment encoding the C $\mu$  portion. Preferably, the last amino acid of a CH3 exon of the IgG or IgA portion is fused in frame to the first amino acid of a C $\mu$ 3 exon. The N-terminus of the segment encoding the hybrid constant region can be fused to a DNA segment encoding a binding region, which can be a heavy chain variable region in the case of an antibody or other binding region (e.g., an extracellular region of a cell surface receptor) in the case of fusion protein. In a single-chain antibody, a DNA construct encoding at least the light chain variable region can be fused in frame with the segment encoding the heavy chain. Alternatively, the light chain can be expressed separately, either as a different expression unit on the same vector as the heavy chain or on a separate vector. As in conventional antibody production, DNA segments encoding an antibody chain or fusion protein are typically operably linked at the N-terminus to a DNA segment encoding a signal peptide to allow secretion.

**[00114]** The order in which fusions of genetic elements is performed in building a construct encoding several components is not important. For example, a DNA segment encoding a heavy chain variable region can be linked to DNA encoding an IgG portion of a hybrid constant region, which can in turn linked to DNA encoding an IgM portion, or the segments encoding a hybrid constant region can be linked to one another first. The segments can also be linked simultaneously by joining overlapping oligonucleotides encoding the respective segments in an overlapping PCR-type reaction. In practice, once an expression vector encoding a hybrid constant region has been produced, the same vector can be used to insert any heavy chain variable region or other binding region in the case of a fusion protein (and sometimes a light chain variable region) without recreating the DNA segment encoding the hybrid constant region.

**[00115]** Mammalian cells are a preferred host for expressing nucleotide segments encoding antibodies or fusion proteins of the invention (see Winnacker, From Genes to Clones, (VCH Publishers, NY, 1987)). A number of suitable host cell lines capable of

secreting intact heterologous proteins have been developed in the art, and include CHO cell lines, various COS cell lines, HeLa cells, HEK293 cells, L cells, and non-antibody-producing myelomas including Sp2/0 and NS0. Preferably, the cells are nonhuman. The cells used for producing antibodies may or may not endogenously express J chains. If endogenous J chains are not expressed or are expressed at an insufficient level, host cells can be genetically modified to express J chains (i.e., by introducing a construct encoding such). However, host cells not expressing J chains can also be used. Selection of cells with or without J chains affects valency with which antibodies or fusion proteins are produced (e.g., pentamer with J chains and hexamer without). Preferably, an antibody or fusion protein of the invention is expressed from a monoclonal cell line.

**[00116]** Expression vectors for these cells can include expression control sequences, such as an origin of replication, a promoter, an enhancer (Queen et al., *Immunol. Rev.* 89:49 (1986)), and necessary processing information sites, such as ribosome binding sites, RNA splice sites, polyadenylation sites, and transcriptional terminator sequences. Preferred expression control sequences are promoters derived from endogenous genes, cytomegalovirus, SV40, adenovirus, bovine papillomavirus, and the like. See Co et al., *J. Immunol.* 148:1149 (1992).

**[00117]** Cells are transfected with one or more vectors encoding the antibody or fusion protein to be expressed. For a multi-chain antibody, the heavy and light chains can be expressed on the same or separate vectors. For expression of multi-specific complexes, the DNA encoding the components of the complexes (i.e., different antibodies or fusion proteins) can be on the same or different vectors.

**[00118]** Antibody or fusion protein chains are expressed, processed to remove signal peptides, assembled and secreted from host cells. It is believed that multimerization and association with J chains occur at least predominantly within cells so that antibodies or fusion proteins are secreted primarily as multimers, particularly multimers in which five or six units are associated via the C $\mu$  portion of the hybrid constant region.

**[00119]** Antibodies or fusion proteins can be purified from cell culture supernatants by conventional antibody purification methods. If the hybrid constant region includes an IgG portion, then the purification can include a chromatography step using protein A or protein G as the affinity reagent. If the hybrid constant region includes an IgA portion, Jacalin lectin affinity chromatography can be used instead. Conventional antibody purification procedures, such as ion exchange, hydroxyapatite chromatograph or HPLC can also be used (see generally, Scopes, *Protein Purification* (Springer-Verlag, NY, 1982)).

## VI. Targets

**[00120]** Antibodies or fusion proteins incorporating a hybrid constant region can be made to any target molecule. The antibodies or fusion proteins are particularly useful for surface-bound target proteins (e.g., on cells or viruses) in which aggregation of the target protein induces a desired response. The desired response can be, for example, clearing of a cell or virus bearing a target, signal transduction through a receptor, e.g., inducing apoptosis, inhibiting a receptor binding to a ligand or counterreceptor, or internalization of an antibody or fusion protein conjugated to a toxic agent. Antibodies or fusion proteins can be made to the same targets as existing commercial antibodies or fusion proteins or can be derivatized versions of commercial antibodies or fusion proteins in which the existing constant region has been replaced by a hybrid constant region of the present invention. The antibodies or fusion proteins can also aggregate surface-bound antigen indirectly by binding to a target ligand bound to a surface-bound antigen.

**[00121]** To illustrate one possible mechanism of action, an antibody or fusion protein incorporating a hybrid heavy chain constant region of the invention is generated with specificity to a member of the tumor necrosis factor receptor super-family. Such receptors require trimerization for signal transduction. Because the antibody is multivalent (e.g., a pentamer or hexamer) it can multimerize antigens on the surface of tumor cells and induce apoptosis and/or growth arrest of tumor cells. Efficacy of such multivalent antibodies to treat cancer can be studied in mouse xenograft models or other appropriate animal models of cancer.

**[00122]** To illustrate another mechanism, an antibody or fusion protein incorporating a hybrid heavy chain constant region is generated with specificity to an antigen expressed on the surface of immune cells, for example, B cells, T cells, monocytes, neutrophils or dendritic cells. Such an antibody can multimerize the antigen on the surface of immune cells and trigger normal or abnormal signal transduction. Alternatively, such an antibody can trigger internalization of the cell surface antigen. The function of such immune cells is enhanced or suppressed, depending on the antigen, type of cells and epitope bound, resulting in modulation of the immune system. The efficacy of such an antibody to treat immune disorders is studied in appropriate in vitro systems or animal models of an immune disorder.

**[00123]** To illustrate another mechanism, an antibody or fusion protein incorporating a hybrid heavy chain constant region is generated with specificity to an antigen expressed by a pathogen, such as infectious bacteria, yeast, fungus or virus. The antibody neutralizes the

infectious microorganism or virus (e.g., by ADCC, CDC, opsonization, or by inhibiting interaction between the pathogen and a cellular receptor, or by action of a toxic moiety attached to the antibody.) The efficacy of such an antibody to treat infectious diseases can be studied in appropriate in vitro systems or animal models of infection.

**[00124]** Targets of interest include receptors on cancer cells and their ligands or counter-receptors (e.g., CD3, CD20, CD22, CD30, CD34, CD40, CD44, CD52, CD70, CD79a, DR4, DR5, EGFR, CA-125/Muc-16, MC1 receptor, PEM antigen, gp72, EpCAM, Her-2, VEGF or VEGFR, ganglioside GD3, CEA, AFP, CTLA-4, alpha v beta 3, HLA-DR 10 beta, SK-1). Other targets of interest are autoantibodies or T-cell subsets mediating autoimmune disease. Other targets of interest are growth factor receptors (e.g., FGFR, HGFR, PDGFR, EGFR, NGFR, and VEGFR) and their ligands. Other targets are G-protein receptors and include substance K receptor, the angiotensin receptor, the  $\alpha$  and  $\beta$  adrenergic receptors, the serotonin receptors, and PAF receptor. See, e.g., Gilman, Ann. Rev. Biochem. 56:625-649 (1987). Other targets include ion channels (e.g., calcium, sodium, potassium channels), muscarinic receptors, acetylcholine receptors, GABA receptors, glutamate receptors, and dopamine receptors (see Harpold, U.S. Pat. No. 5,401,629 and U.S. Pat. No. 5,436,128). Other targets are adhesion proteins such as integrins, selectins, and immunoglobulin superfamily members (see Springer, Nature 346:425-433 (1990). Osborn, Cell 62:3 (1990); Hynes, Cell 69:11 (1992)). Other targets are cytokines, such as interleukins IL-1 through about IL-37 to-date, tumor necrosis factors, interferon, and, tumor growth factor beta, colony stimulating factor (CSF) and granulocyte monocyte colony stimulating factor (GM-CSF). See Human Cytokines: Handbook for Basic & Clinical Research (Aggrawal et al. eds., Blackwell Scientific, Boston, Mass. 1991). Other targets are amyloidogenic peptides, such as Abeta, alpha-synuclein or prion peptide. Other targets are hormones, enzymes, and intracellular and intercellular messengers, such as, adenyl cyclase, guanyl cyclase, and phospholipase C. Target molecules can be human, mammalian or bacterial. Other targets are antigens, such as proteins, glycoproteins and carbohydrates from microbial pathogens, both viral and bacterial, and tumors.

**[00125]** Some examples of commercial antibodies and their targets include alemtuzumab, CD52, rituximab, CD20, trastuzumab Her/neu, nimotuzumab, cetuximab, EGFR, bevacizumab, VEGF, palivizumab, RSV, abciximab, GpIIb/IIIa, infliximab, adalimumab, certolizumab, golimumab TNF-alpha, baciliximab, daclizumab, IL-2, omalizumab, IgE, gemtuzumab, CD33, natalizumab, VLA-4, vedolizumab alpha4beta7, belimumab, BAFF, otelixizumab, teplizumab CD3, ofatumumab, ocrelizumab CD20,

epratuzumab CD22, alemtuzumab CD52, eculizumab C5, canakinumab IL-1beta, mepolizumab IL-5, reslizumab, tocilizumab IL-6R, ustekinumab, briakinumab IL-12, 23. Examples of commercial fusion proteins include etanercept which binds TNF-alpha, alefacept (LFA3-Fc fusion which binds CD2), TACI-Fc fusion which binds BAFF and APRIL, abatacept (CTLA-4-Fc which binds CD80 and CD86), and romiplostim (a peptide analog of thrombopoietin fused to Fc). Any of the commercial antibodies or fusion protein can be modified to replace the existing heavy chain constant region with a hybrid constant region of the invention. Alternatively, a hybrid constant region can be linked to other antibodies with the same target specificity (e.g., as determined by a competition assay) as any of the above commercial antibodies or fusion proteins.

## VII. Immunoconjugates

**[00126]** Antibodies or fusion proteins can be conjugated to a toxic agent. Toxic agents can be cytotoxic or cystostatic. Some example of toxic agents include antitubulin agents, auristatins, DNA minor groove binders, DNA replication inhibitors, alkylating agents (e.g., platinum complexes such as cis-platin, mono(platinum), bis(platinum) and tri-nuclear platinum complexes and carboplatin), anthracyclines, antibiotics, antifolates, antimetabolites, chemotherapy sensitizers, duocarmycins, camptothecins, etoposides, fluorinated pyrimidines, ionophores, lexitropsins, nitrosoureas, platinols, pre-forming compounds, purine antimetabolites, puromycins, radiation sensitizers, steroids, taxanes, topoisomerase inhibitors, vinca alkaloids, or the like. A variety of radionuclides are available for the production of radioconjugated antibodies. Examples include  $^{212}\text{Bi}$ ,  $^{131}\text{I}$ ,  $^{131}\text{In}$ ,  $^{90}\text{Y}$ , and  $^{186}\text{Re}$ . Conjugates of an antibody and toxic agent can be made using a variety of bifunctional protein-coupling agents such as N-succinimidyl-3-(2-pyridyldithiol) propionate (SPDP), iminothiolane (IT), bifunctional derivatives of imidoesters (such as dimethyl adipimidate HCl), active esters (such as disuccinimidyl suberate), aldehydes (such as glutaraldehyde), bis-azido compounds (such as bis(p-azidobenzoyl)hexanediamine), bis-diazonium derivatives (such as bis-(p-diazoniumbenzoyl)-ethylenediamine), diisocyanates (such as toluene 2,6-diisocyanate), and bis-active fluorine compounds (such as 1,5-difluoro-2,4-dinitrobenzene). A toxic agent can also be linked to an antibody via a linker, which may be cleavable under intracellular conditions (US 2003-0083263, 2005-0238649 and 2005-0009751). Many of the above toxic agents are only effective or most effective when internalized within a cell. The antibodies or fusion proteins of the invention can be internalized by binding to cellular receptors, for example, crosslinking of cellular receptors can promote internalization.

### VIII. Methods of Treatment and Pharmaceutical Compositions

**[00127]** The antibodies or fusion proteins of the invention can be used for treating cancers including those for which commercial antibodies mentioned above have been used. The methods can be used to treat solid tumors, and particularly hematological malignancies, such as leukemia (e.g., T cell large granular lymphocyte leukemia), lymphoma (Hodgkin's or Non-Hodgkin's), or multiple myeloma. Solid tumors include skin (e.g., melanoma), ovarian, endometrial, bladder, breast, rectum, colon, gastric, pancreatic, lung, thymus, kidney and brain.

**[00128]** The antibodies and fusion protein of the invention can also be used for suppressing various undesirable immune responses including those in which the commercial antibodies mentioned above have been used.

**[00129]** One category of immune disorders treatable by antibodies or fusion proteins of the invention is transplant rejection. When allogeneic cells or organs (e.g., skin, kidney, liver, heart, lung, pancreas and bone marrow) are transplanted into a host (i.e., the donor and donee are different individual from the same species), the host immune system is likely to mount an immune response to foreign antigens in the transplant (host-versus-graft disease) leading to destruction of the transplanted tissue. The antibodies of the present invention are useful, *inter alia*, to block alloantigen-induced immune responses in the donee.

**[00130]** A related use for antibodies or fusion proteins of the present invention is in modulating the immune response involved in "graft versus host" disease (GVHD). GVHD is a potentially fatal disease that occurs when immunologically competent cells are transferred to an allogeneic recipient. In this situation, the donor's immunocompetent cells may attack tissues in the recipient. Tissues of the skin, gut epithelia and liver are frequent targets and may be destroyed during the course of GVHD. The disease presents an especially severe problem when immune tissue is being transplanted, such as in bone marrow transplantation; but less severe GVHD has also been reported in other cases as well, including heart and liver transplants.

**[00131]** A further situation in which immune suppression is desirable is in treatment of autoimmune diseases such as type 1 diabetes, Crohn's disease, ulcerative colitis, multiple sclerosis, stiff man syndrome, rheumatoid arthritis, myasthenia gravis and lupus erythematosus. In these diseases, the body develops a cellular and/or humoral immune response against one of its own antigens leading to destruction of that antigen, and potentially

crippling and/or fatal consequences. Autoimmune diseases are treated by administering one of the antibodies or fusion proteins of the invention.

**[00132]** Other immune disorders treatable by antibodies or fusion proteins of the invention, include asthma, allergies, celiac disease, psoriasis, and uveitis. Celiac disease, psoriasis and uveitis are autoimmune diseases.

**[00133]** The antibodies or fusion protein can also be used for treatment of pathogenic infections, such as viral, bacterial, protozoan or fungal infection. Some example of viral infections include HIV, hepatitis (A, B, or C), herpes virus (e.g., VZV, HSV-1, HAV-6, HSV-II, CMV, and Epstein Barr virus), adenovirus, XMRV, influenza virus, flaviviruses, echovirus, rhinovirus, coxsackie virus, cornovirus, respiratory syncytial virus, mumps virus, rotavirus, measles virus, rubella virus, parvovirus, vaccinia virus, HTLV virus, dengue virus, MLV-related Virus, papillomavirus, molluscum virus, poliovirus, rabies virus, JC virus and arboviral encephalitis virus. Some examples of bacterial infections include chlamydia, rickettsial bacteria, mycobacteria, staphylococci, streptococci, pneumonococci, meningococci and conococci, klebsiella, proteus, serratia, pseudomonas, legionella, diphtheria, salmonella, bacilli, cholera, tetanus, botulism, anthrax, plague, leptospirosis, Lymes disease bacteria, streptococci, or neisseria. Some examples of pathogenic fungi include Candida, Aspergillus, Cryptococcus, Histoplasma, Pneumocystis and Stachybotrys. Examples of protozoa include Cryptosporidium, Giardia lamblia and plasmodium.

**[00134]** Antibodies or fusion proteins are administered in an effective regime meaning a dosage, route of administration and frequency of administration that delays the onset, reduces the severity, inhibits further deterioration, and/or ameliorates at least one sign or symptom of a disorder. If a patient is already suffering from a disorder, the regime can be referred to as a therapeutically effective regime. If the patient is at elevated risk of the disorder relative to the general population but is not yet experiencing symptoms, the regime can be referred to as a prophylactically effective regime. In some instances, therapeutic or prophylactic efficacy can be observed in an individual patient relative to historical controls or past experience in the same patient. In other instances, therapeutic or prophylactic efficacy can be demonstrated in a preclinical or clinical trial in a population of treated patients relative to a control population of untreated patients.

**[00135]** Exemplary dosages for an antibody or fusion protein are 0.01-20, or 0.5-5, or 0.01-1, or 0.01-0.5 or 0.05-0.5 mg/kg body weight (e.g., 0.1, 0.5, 1, 2, 3, 4 or 5 mg/kg) or 10-1500 mg as a fixed dosage. The dosage depends on the condition of the patient and response

to prior treatment, if any, whether the treatment is prophylactic or therapeutic and whether the disorder is acute or chronic, among other factors.

**[00136]** Administration can be parenteral, intravenous, oral, subcutaneous, intra-arterial, intracranial, intrathecal, intraperitoneal, topical, intranasal or intramuscular. Administration into the systemic circulation by intravenous or subcutaneous administration is preferred.

Intravenous administration can be, for example, by infusion over a period such as 30-90 min.

**[00137]** The frequency of administration depends on the half-life of the antibody or fusion protein in the circulation, the condition of the patient and the route of administration among other factors. The frequency can be daily, weekly, monthly, quarterly, or at irregular intervals in response to changes in the patient's condition or progression of the disorder being treated. An exemplary frequency for intravenous administration is between weekly and quarterly over a continuous course of treatment, although more or less frequent dosing is also possible. For subcutaneous administration, an exemplary dosing frequency is daily to monthly, although more or less frequent dosing is also possible.

**[00138]** The number of dosages administered depends on whether the disorder is acute or chronic and the response of the disorder to the treatment. For acute disorders or acute exacerbations of chronic disorders between 1 and 10 doses are often sufficient. Sometimes a single bolus dose, optionally in divided form, is sufficient for an acute disorder or acute exacerbation of a chronic disorder. Treatment can be repeated for recurrence of an acute disorder or acute exacerbation. For chronic disorders, an antibody can be administered at regular intervals, e.g., weekly, fortnightly, monthly, quarterly, every six months for at least 1, 5 or 10 years, or the life of the patient.

**[00139]** Pharmaceutical compositions for parenteral administration are preferably sterile and substantially isotonic and manufactured under GMP conditions. Pharmaceutical compositions can be provided in unit dosage form (i.e., the dosage for a single administration). Pharmaceutical compositions can be formulated using one or more physiologically acceptable carriers, diluents, excipients or auxiliaries. The formulation depends on the route of administration chosen. For injection, antibodies can be formulated in aqueous solutions, preferably in physiologically compatible buffers such as Hank's solution, Ringer's solution, or physiological saline or acetate buffer (to reduce discomfort at the site of injection). The solution can contain formulatory agents such as suspending, stabilizing and/or dispersing agents. Alternatively antibodies can be in lyophilized form for constitution with a suitable vehicle, e.g., sterile pyrogen-free water, before use.

**[00140]** Treatment with antibodies of the invention can be combined with other treatments effective against the disorder being treated. For treatment of immune disorders, conventional treatments include mast cell degranulation inhibitors, corticosteroids, nonsteroidal anti-inflammatory drugs, and stronger anti-inflammatory drugs such as azathioprine, cyclophosphamide, leukeran, FK506 and cyclosporine. Biologic anti-inflammatory agents, such as Tysabri® (natalizumab) or Humira® (adalimumab), can also be used. When used in treating cancer, the antibodies of the invention can be combined with chemotherapy, radiation, stem cell treatment, surgery or treatment with other biologics such as Herceptin® (trastuzumab) against the HER2 antigen, Avastin® (bevacizumab) against VEGF, or antibodies to the EGF receptor, such as (Erbitux®, cetuximab), and Vectibix® (panitumumab). Chemotherapy agents include chlorambucil, cyclophosphamide or melphalan, carboplatinum, daunorubicin, doxorubicin, idarubicin, and mitoxantrone, methotrexate, fludarabine, and cytarabine, etoposide or topotecan, vincristine and vinblastine. For infections, treatment can be in combination with antibiotics, anti-virals, anti-fungal or antiProtozoan agents or the like.

#### IX. Other applications

**[00141]** The antibodies or fusion proteins can be used for detecting their target molecule in the context of clinical diagnosis or treatment or in research. For example, the antibodies can be used to detect a cancer-related antigen as an indication a patient is suffering from an immune mediated disorder amenable to treatment. The antibodies can also be sold as research reagents for laboratory research in detecting targets and their response to various stimuli. In such uses, antibodies or fusion proteins can be labeled with fluorescent molecules, spin-labeled molecules, enzymes or radioisotypes, and can be provided in the form of kit with all the necessary reagents to perform the assay. The antibodies or fusion protein can also be used to purify their target antigens e.g., by affinity chromatography.

**[00142]** All patent filings, websites, other publications, accession numbers and the like cited above or below are incorporated by reference in their entirety for all purposes to the same extent as if each individual item were specifically and individually indicated to be so incorporated by reference. If different versions of a sequence are associated with an accession number at different times, the version associated with the accession number at the effective filing date of this application is meant. The effective filing date means the earlier of the actual filing date or filing date of a priority application referring to the accession number if applicable. Likewise if different versions of a publication, website or the like are

published at different times, the version most recently published at the effective filing date of the application is meant unless otherwise indicated. Any feature, step, element, embodiment, or aspect of the invention can be used in combination with any other unless specifically indicated otherwise. Although the present invention has been described in some detail by way of illustration and example for purposes of clarity and understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims.

## EXAMPLES

### **Example 1: Expression vectors**

**[00143]** Gene cloning, mutagenesis and plasmid construction in this work was carried out with standard molecular biology techniques. See Sambrook and Russel (Molecular Cloning, A Laboratory Manual, 3rd ed., 2001, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY), Kostelny et al. (Int. J. Cancer 93:556-565, 2001), and Cole et al. (J. Immunol. 159:3613-3621, 1997), which are incorporated herein by references.

**[00144]** The mammalian expression vector pCh9G6-IgG1 (Fig. 1) for production of a chimeric IgG1 form of the mouse anti-human CD79a monoclonal antibody 9G6 (Ch9G6-IgG1) was constructed to contain the following genetic components. Proceeding clockwise from the SalI site of pCh9G6-IgG1 in Fig. 1, the plasmid contains the heavy chain transcription unit starting with the human cytomegalovirus (CMV) major immediate early promoter and enhancer (CMV-P in the figure) to initiate transcription of the antibody heavy chain gene. The CMV promoter is followed by the heavy chain variable region exon of the mouse anti-human CD79a monoclonal antibody 9G6 (9G6 VH) flanked by the SpeI and HindIII sites, a genomic sequence containing the human  $\gamma$ -1 heavy chain constant regions including the CH1 (CH1( $\gamma$ 1)), hinge (h( $\gamma$ 1)), CH2 (CH2( $\gamma$ 1)) and CH3 (CH3( $\gamma$ 1)) exons with the intervening introns, and the polyadenylation site of the human  $\gamma$ -1 heavy chain gene. After the heavy chain gene sequence, the light chain transcription unit begins with the CMV promoter (CMV-P), followed by the light chain variable region exon of the mouse anti-human CD79a monoclonal antibody 9G6 (9G6 VL) flanked by the NheI and EcoRI sites, a genomic sequence containing the human kappa chain constant region exon (CL) with part of the intron preceding it, and the polyadenylation site of the human kappa chain gene following the CL exon. The light chain gene is then followed by the SV40 early promoter (SV40-P), the E. coli xanthine guanine phosphoribosyl transferase gene (gpt), and a segment containing

the SV40 polyadenylation site (SV40-A). Finally, the plasmid contains a part of the plasmid pUC19, comprising the bacterial origin of replication (pUC ori) and the  $\beta$  lactamase gene ( $\beta$  lactamase). Arrows in the figure indicate the orientation of transcription.

**[00145]** The mouse hybridoma producing anti-human CD79a monoclonal IgG antibody 9G6 was created at JN Biosciences (Mountain View, CA) using recombinant human CD79a proteins as immunogens and following standard hybridoma techniques. The VH and VL sequences were determined by standard experimental procedures such as the method described by Tsurushita et al. (Methods 36:69-83, 2005). The 9G6 VH gene in the SpeI-HindIII fragment was designed as an exon including a splice donor signal at the 3' end of the coding region. The amino acid sequence of 9G6 VH, including the signal peptide, encoded by the VH exon in pCh9G6-IgG1 is shown below. The mature 9G6 VH sequence starts at position 20 in SEQ ID NO:1.

**[00146]** Amino acid sequence of 9G6 VH (SEQ ID NO:1):

MGWSRIFLFLLSITAGVHCQVQLQQSGPELVKPGASVKISCKASGYTFSTSWMNWV  
KQRPGQGLEWIGRIYPGDGDTNYNGKFKGKATLTADKSSNTAYMQLSSLTSVDSA  
YFCERFYGGNTFAMDYWGQGTSVTVSS

**[00147]** The 9G6 VL gene in the NheI-EcoRI fragment was also designed as an exon including a splice donor signal at the 3' end of the coding region. The amino acid sequence of 9G6 VL, including the signal peptide, encoded by the VL exon in pCh9G6-IgG1 is shown below. The mature 9G6 VL sequence starts at position 20 in SEQ ID NO:2.

**[00148]** Amino acid sequence of 9G6 VL (SEQ ID NO:2):

MKLPVRLVLMFWIPASSSDVLMQTQIPLSLPVSLGDQASISCRSSQSIVHSNGNTYLE  
WYLQKPGQSPKLLIYKVSNRFSGVPDRFSGSGSGTDFTLKISRVEAEDLGVYYCFQG  
SHVPFTFGSGTKLEIKR

**[00149]** The amino acid sequence of the immunoglobulin heavy chain constant region encoded in pCh9G6-IgG1 is shown below.

**[00150]** Heavy chain constant region encoded in pCh9G6-IgG1 (SEQ ID NO:3):

ASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTWNSGALTSGVHTFPAVL  
QSSGLYSLSSVVTVPSSSLGTQTYICNVNHKPSNTKVDKKVEPKSCDKTHTCPPCPAP  
ELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAK  
TKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQP  
PQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTPVLDSDG  
SFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK

**[00151]** The amino acid sequence of the immunoglobulin light chain constant region encoded in pCh9G6-IgG1 is shown below.

**[00152]** Light chain constant region encoded in pCh9G6-IgG1 (SEQ ID NO:4):  
TVAAPSVFIFPPSDEQLKSGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTE  
QDSKDSTYSLSSTLTLKADYEKHKVYACEVTHQGLSSPVTKSFNRGEC

**[00153]** The expression vector pCh9G6-IgG1 was modified to construct a new expression vector pCh9G6-IgG1/M in such a way that a cDNA-derived fragment encoding the CH3 and CH4 regions of the human  $\mu$  heavy chain (C $\mu$ 3 and C $\mu$ 4, respectively) was fused in frame to the last amino acid of the hinge region in pCh9G6-IgG1. The amino acid sequence of C $\mu$ 3 and C $\mu$ 4 is shown below.

**[00154]** C $\mu$ 3 and C $\mu$ 4 of the human  $\mu$  heavy chain (SEQ ID NO:5):  
DQDTAIRVFAIPPSFASIFLTKSTKLTCLVTDLTTYDSVTISWTRQNGEAVKTHTNISES  
HPNATFSAVGEASICEDDWNSGERFTCTVHTDLPSPLKQTISRPKGVALHRPDVYLL  
PPAREQLNLRESATITCLVTGFSPADVQWMQRGQPLSPEKYVTSAPMPEPQAPGR  
YFAHSILTVSEEEWNTGETYTCVVAHEALPNRVTERTVDKSTGKPTLYNVSLVMSDT  
AGTCY

**[00155]** The CH2 and CH3 exons of the human  $\gamma$ -1 heavy chain were deleted in pCh9G6-IgG1/M. The light chain sequence of pCh9G6-IgG1 was not modified in pCh9G6-IgG1/M. The schematic structure of pCh9G6-IgG1/M is shown in Fig. 1. The structure of the heavy chain constant region encoded in pCh9G6-IgG1/M includes from the N-terminus to the C-terminus, the CH1 and hinge regions of the human gamma-1 heavy chain, and the C $\mu$ 3 and C $\mu$ 4 regions. The amino acid sequence of the heavy chain constant region encoded in pCh9G6-IgG1/M is shown below.

**[00156]** Heavy chain constant region encoded in pCh9G6-IgG1/M (SEQ ID NO:6):  
ASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTVWSNSGALTSGVHTFPAVL  
QSSGLYSLSSVVTVPSSSLGTQTYICNVNHKPSNTKVDKKVEPKSCDKTHTCPPCPDQ  
DTAIRVFAIPPSFASIFLTKSTKLTCLVTDLTTYDSVTISWTRQNGEAVKTHTNISESHP  
NATFSAVGEASICEDDWNSGERFTCTVHTDLPSPLKQTISRPKGVALHRPDVYLLPP  
AREQLNLRESATITCLVTGFSPADVQWMQRGQPLSPEKYVTSAPMPEPQAPGRYF  
AHSILTVSEEEWNTGETYTCVVAHEALPNRVTERTVDKSTGKPTLYNVSLVMSDTA  
GTCY

**[00157]** The expression vector pCh9G6-IgG1 was also modified in such a way that the coding region of C $\mu$ 3 and C $\mu$ 4 was fused in frame to the last amino acid of the CH3 exon in pCh9G6-IgG1. The light chain sequence was not modified. The schematic structure of the

resulting plasmid, pCh9G6-MVIgG1, is shown in Fig. 1. The amino acid sequence of the heavy chain constant region encoded in pCh9G6-MVIgG1 is shown below.

**[00158]** Heavy chain constant region encoded in pCh9G6-MVIgG1 (SEQ ID NO:7):  
ASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTWSWNSGALTSGVHTFPAVL  
QSSGLYSLSSVVTVPSSSLGTQTYICNVNHKPSNTKVDKKVEPKSCDKTHTCPPCPAP  
ELLGGPSVFLPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAK  
TKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTIASKAQPRE  
PQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTPVLDSDG  
SFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSPGKDQDTAIRVFAIP  
PSFASIFLTKSTKLTCLVTDLTTYDSVTISWTRQNGEAVKTHTNISESHPNATFSAVGE  
ASICEDDWNSGERFTCTVHTDLPPLKQTISRPKGVALHRPDVYLLPPAREQLNLRE  
SATITCLVTGFSPADVFVQWMQRGQPLSPEKYVTSAPMPEPQAPGRYFAHSILTVSEE  
EWNTGETYTCVVAHEALPNRVTERTVDKSTGKPTLYNVSLVMSDTAGTCY

**[00159]** The schematic structure of the monomer form of the antibodies produced from pCh9G6-IgG1, pCh9G6-IgG1/M and pCh9G6-MVIgG1 (Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1, respectively) is shown in Fig. 2. The symbols “CH1”, “hinge”, “CH2” and “CH3” in the figure denote the CH1, hinge, CH2 and CH3 regions of human gamma heavy chains, respectively. The symbols “C $\mu$ 3” and “C $\mu$ 4” denote the CH3 and CH4 regions of the human  $\mu$  heavy chain, respectively. The symbol “CL” denotes the human kappa constant region.

**Example 2: Expression, purification and characterization of multivalent anti-CD79a IgG1 antibodies**

**[00160]** The expression vectors pCh9G6-IgG1, pCh9G6-IgG1/M and pCh9G6-MVIgG1 were introduced into the chromosome of a mouse myeloma cell line NS0 (European Collection of Animal Cell Cultures, Salisbury, Wiltshire, UK) to obtain cell lines stably producing Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1 antibodies, respectively. NS0 cells were grown in DME medium containing 10% fetal bovine serum (FBS; HyClone, Logan, UT) at 37°C in a 7.5% CO<sub>2</sub> incubator. Stable transfection into NS0 was carried out by electroporation as described in Bebbington et al. (Bio/Technology 10: 169-175, 1992). Before transfection, each expression vector was linearized using FspI. In a typical experiment, approximately 10<sup>7</sup> cells were transfected with 20  $\mu$ g of linearized plasmid, suspended in DME medium containing 10% FBS, and plated into several 96-well plates. After 48 hr, selection media (DME medium containing 10% FBS, HT media supplement

(Sigma, St. Louis, MO), 0.25 mg/ml xanthine and 1  $\mu$ g/ml mycophenolic acid) was applied. Approximately 10 days after the initiation of selection, culture supernatants of transfectants were assayed for antibody production.

**[00161]** Expression of antibodies was measured by sandwich ELISA. In a typical experiment, an ELISA plate was coated overnight at 4°C with 100  $\mu$ l/well of 1/2,000-diluted goat anti-human IgG Fc $\gamma$ -chain-specific (for Ch9G6-IgG1 and Ch9G6-MVIgG1 antibodies) or anti-human IgM Fc $\mu$ -chain-specific (for Ch9G6-IgG1/M) polyclonal antibody in PBS (phosphate-buffered saline, pH 7.4), washed with Wash Buffer (PBS containing 0.05% Tween 20), and blocked for 0.5 hr at room temperature with 200  $\mu$ l/well of Block Buffer (PBS containing 2% Skim Milk and 0.05% Tween 20). After washing with Wash Buffer, 100  $\mu$ l/well of test samples appropriately diluted in ELISA Buffer (PBS containing 1% Skim Milk and 0.025% Tween 20) were applied to the ELISA plate. An appropriate human IgG/ $\kappa$  or IgM/ $\kappa$  antibody was used as a standard. After incubating the ELISA plate for 1 hr at room temperature and washing with Wash Buffer, bound antibodies were detected using 100  $\mu$ l/well of 1/2,000-diluted HRP-conjugated goat anti-human kappa chain polyclonal antibody in ELISA buffer. After incubating for 1 hr at room temperature and washing with Wash Buffer, color development was performed by adding 100  $\mu$ l/well of ABTS substrate. Color development was stopped by adding 100  $\mu$ l/well of 2% oxalic acid. Absorbance was read at 405 nm.

**[00162]** NS0 stable transfectants producing each of Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1 antibodies were adapted to growth in serum-free media using Hybridoma SFM (Invitrogen) and cultured in a roller bottle to the density of about 10<sup>6</sup>/ml, fed with 1/10th volume of 60 mg/ml of Ultrafiltered Soy Hydrolysate (Irvine Scientific, Santa Ana, CA) dissolved in SFM4MAb media (HyClone), and grown further until the cell viability became less than 50%. After centrifugation and filtration, culture supernatant was loaded onto a Protein A column (HiTrap MABSelect SuRe, GE Healthcare, Piscataway, NJ) for Ch9G6-IgG1 and Ch9G6-MVIgG1. The column was washed with PBS before the antibody was eluted with 0.1 M glycine-HCl (pH 3.0). Since Ch9G6-IgG1/M, which lacks the CH2 and CH3 regions of the human gamma-1 heavy chain, did not bind to protein A, culture supernatant of NS0 stable transfectants producing Ch9G6-IgG1/M was loaded onto a goat anti-human IgM agarose column (Sigma). The anti-human IgM agarose column was washed with PBS before the antibody was eluted with 0.1 M glycine-HCl (pH 2.5). The buffer of all eluted antibodies was neutralized with 1 M Tris-HCl (pH 8) and then changed to PBS by dialysis. Antibody concentration was determined by measuring absorbance at 280 nm (1

mg/ml = 1.4 OD). Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1 were confirmed to bind specifically to human CD79a.

**[00163]** Purified Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1 antibodies were characterized by SDS-PAGE according to standard procedures. Analysis under reducing conditions indicated that each antibody is comprised of two chains. The molecular weight of each chain was estimated by comparing the mobility on the gel to that of molecular weight markers. The light chain, which is common among Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1, was estimated to have a molecular weight of approximately 26 kDa. The molecular weight of the heavy chain was estimated to be 54 kDa for Ch9G6-IgG1, 58 kDa for Ch9G6-IgG1/M, and 76 kDa for Ch9G6-MVIgG1. The estimated molecular weight of each of the light and heavy chains is in agreement with the expected molecular weight based on the corresponding amino acid sequence.

**[00164]** The molecular size of Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1 in the native form was analyzed by gel filtration using the AKTA Basic FPLC system with a Superose 6 10/300 GL column which has a separation range from 5 kDa to 5,000 kDa of globular proteins (GE Healthcare, Indianapolis, IN). PBS was used as elution buffer. Figs. 3C-E shows the elution patterns of Ch9G6-IgG1 (Fig. 3C), Ch9G6-IgG1/M (Fig. 3D) and Ch9G6-MVIgG1 (Fig. 3E). Only one dominant peak was observed for each of Ch9G6-IgG1 (at 16.7 ml of elution) and Ch9G6-MVIgG1 (at 9.9 ml), whereas two major and several minor peaks existed for Ch9G6-IgG1/M. Human monoclonal IgM antibody purified from a myeloma cell line (Jackson ImmunoResearch, West Grove, PA) was eluted at 10.4 ml (Fig. 3B). By comparing to the elution pattern of the molecular weight standards (Gel Filtration Standard, BioRad, Hercules, CA) (Fig. 3A), the molecular weight of Ch9G6-IgG1/M in the two major peaks at 11.7 ml and 14.8 ml of elution was estimated to be approximately 800 kDa and 220 kDa, respectively. The molecular weight of Ch9G6-IgG1 in the dominant peak was estimated to be 154 kDa, which corresponds to the predicted molecular weight of a monomer of Ch9G6-IgG1 (160 kDa) based on the size of its heavy and light chain on SDS-PAGE. Ch9G6-MVIgG1 was eluted at 9.9 ml while human IgM was eluted at 10.4 ml, indicating that Ch9G6-MVIgG1 is slightly larger than human IgM. Since the SDS-PAGE analysis indicated that the molecular weight of the heavy and light chains of Ch9G6-MVIgG1 was 76 kDa and 26kDa, respectively, the molecular weight of a monomer of Ch9G6-MVIgG1 is calculated to be approximately 200 kDa, which is slightly larger than the monomer of human IgM (roughly 180 kDa). As human IgM purified from myeloma cells is likely to exist as a pentamer (or possibly as a hexamer), it was therefore concluded that

Ch9G6-MVIgG1 purified from NS0 cells also existed as a pentmer or hexamer in the native form.

### **Example 3: Apoptosis by multivalent anti-CD79a IgG1 antibodies**

**[00165]** The human Burkitt's lymphoma cell line Ramos expresses on the cell surface B cell receptors composed of membrane-bound IgM/lambda, CD79a and CD79b proteins (Ollila et al., Mol. Immunol. 44:3537-3551, 2007; Reth, Annu. Rev. Immunol. 10:97-121, 1992). Multimerization of B cell receptors by cross-linking is known to induce apoptosis of Ramos cells (Ollia et al., *supra*).

**[00166]** Ramos cells were grown in DME media containing 10% FBS. To assess the ability of Ch9G6-IgG1 and Ch9G6-MVIgG1 antibodies to multimerize B cell receptors on the cell surface via binding to CD79a proteins, resulting in induction of apoptosis, each antibody was incubated with Ramos cells in triplicate at a final concentration of 1 µg/ml. Ch9G6-IgG1 was also added at 1 µg/ml together with 10 µg/ml of goat anti-human IgG polyclonal antibody for cross-linking. As a positive control of apoptosis, 1 µg/ml goat anti-human lambda light chain polyclonal antibody was incubated with Ramos cells. After culturing in a 7.5% CO<sub>2</sub> incubator for 3 days, cell viability was measured with alamarBlue (Invitrogen) according to the manufacturer's protocol.

**[00167]** Percent cell viability was calculated by normalizing the absorbance value in the presence of test antibodies to that in the absence of test antibodies. The absorbance value with no cells was used as background. The viability was 69 % for goat anti-human lambda light chain polyclonal antibody ("Anti-lambda pAb" in the figure), 107% for Ch9G6-IgG1, 42% for a mixture of Ch9G6-IgG1 and goat anti-human IgG polyclonal antibody ("Ch9G6-IgG1 + Anti-human IgG" in the figure), and 53% for Ch9G6-MVIgG1. Divalent Ch9G6-IgG1 did not induce apoptosis of Ramos cells, whereas cross-linked Ch9G6-IgG1 was able to induce apoptosis. Ch9G6-MVIgG1 induced apoptosis of Ramos cells almost as efficiently as cross-linked Ch9G6-IgG1 did. Ch9G6-MVIgG1 functioned as a multivalent anti-CD79a antibody is capable of multimerizing B cell receptors on the cell surface and inducing apoptosis of Ramos cells (Fig. 4).

### **Example 4: Binding of multivalent IgG1 antibodies to neonatal Fc receptors**

**[00168]** The ability of Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1 antibodies to bind to FcRn in a pH-dependent manner was analyzed by flow cytometry using NS0 cells expressing human FcRn on the cell surface (NS0/FcRn cells). NS0/FcRn transfectants stably

expressing human FcRn, a heterodimer composed of the FcRn  $\alpha$  chain and  $\beta 2$ -microglobulin, on the cell surface was generated following the general procedure described by Hinton et al. (J. Biol. Chem. 279:6213-6216 2004), which is incorporated herein by reference. Ch9G6-IgG1, Ch9G6-IgG1/M and Ch9G6-MVIgG1 at 1  $\mu$ g/ml were separately incubated with NS0/FcRn cells at pH 6.0 and 7.5 at the primary staining step following the procedure described by Hinton et al. (supra). Antibodies binding to FcRn were detected using PE-labeled goat polyclonal anti-human gamma chain antibody (for Ch9G6-IgG1 and no antibody control) or PE-labeled goat polyclonal anti-human  $\mu$  chain antibody (for Ch9G6-IgG1/M, Ch9G6-MVIgG1 and no antibody control) at the secondary staining step. As shown in Fig. 5, both Ch9G6-IgG1 and Ch9G6-MVIgG1 bound strongly to FcRn at pH 6.0. Their FcRn binding was significantly weaker at pH 7.5 than at pH 6.0, exhibiting pH-dependent binding to FcRn, indicating that these antibodies have a long serum half-life. Ch9G6-IgG1/M hardly bound to FcRn at both pH 6.0 and 7.5, indicating a short serum half-life of Ch9G6-IgG1/M. This is consistent with the fact that Ch9G6-IgG1/M lacks the binding site to FcRn.

#### **Example 5: Binding of multivalent IgG1 antibodies to CD16**

**[00169]** Interaction of the Fc region of cell-bound IgG1 and IgG3 antibodies with CD16 molecules (also called Fc $\gamma$  receptor type III) expressed on the surface of NK cells triggers antibody-dependent cell-mediated cytotoxicity (ADCC) by NK cells against antibody-bound cells in humans (Hulett et al., Adv. Immunol. 57:1-127, 1994). The CD16 binding site exists at the lower hinge encoded in the CH2 region of the human gamma-1 and gamma-3 chains (Sarmay et al., Mol. Immunol. 29:633-639, 1992).

**[00170]** Binding of multivalent IgG1 antibodies to human CD16 was analyzed by flow cytometry. HEK293 cells transiently expressing human CD16 on the surface were incubated with 1  $\mu$ g/ml of Ch9G6-IgG1, Ch9G6-IgG1/M, Ch9G6-MVIgG1, or the mouse monoclonal anti-human CD16 IgG antibody 3G8 (BioLegend, San Diego, CA) in FACS Buffer (PBS containing 0.5 % bovine serum albumin and 0.025% sodium azide) for 30 min on ice at the primary antibody binding step. As a control, HEK293 cells expressing human CD16 were also incubated without test antibodies. After washing with FACS buffer, cells were incubated with phycoerythrin (PE)-labeled goat polyclonal anti-human gamma heavy chain antibody (for Ch9G6-IgG1, Ch9G6-MVIgG1, and no antibody control), PE-labeled goat polyclonal anti-human  $\mu$  heavy chain antibody (for Ch9G6-IgG1/M, Ch9G6-MVIgG1, and no antibody control) or PE-labeled goat polyclonal anti-mouse gamma heavy chain antibody

in FACS buffer for 15 min on ice at the secondary staining step. After washing with FACS buffer, stained cells were suspended in FACS buffer and analyzed by flow cytometry.

**[00171]** The mouse anti-CD16 antibody bound strongly to HEK293 cells transiently expressing human CD16 (Fig. 6I). Ch9G6-IgG1 also showed a strong binding to human CD16 (Fig. 6D). Ch9G6-MVIgG1 showed even a stronger binding to CD16 than Ch9G6-IgG1 did (Fig. 6F), indicating the capability of exerting ADCC. On the other hand, Ch9G6-IgG1/M showed only marginal binding to human CD16 (Fig. 6E) when compared the cells stained with PE-labeled goat anti- $\mu$  heavy chain antibody alone (Fig. 6C). The apparent weak binding of Ch9G6-IgG1/M to CD16 is not due to PE-labeled goat anti- $\mu$  heavy chain antibody because strong CD16 binding of Ch9G6-MVIgG1 was observed when PE-labeled goat anti- $\mu$  heavy chain antibody was used at the secondary staining step (Fig. 6G). The inability of Ch9G6-IgG1/M to bind to CD16, which results in no ADCC activity, is consistent with the fact that Ch9G6-IgG1/M lacks the CH2 and CH3 regions of the human gamma-1 heavy chain.

**Example 6: Generation, expression, purification and characterization of multivalent anti-CD30 IgG1 antibodies**

**[00172]** The mouse hybridoma producing the anti-human CD30 monoclonal antibody San11 was isolated at JN Biosciences using recombinant human CD30 proteins as immunogens and following standard hybridoma techniques. The San11 VH and VL sequences were determined by standard experimental procedures such as the method described by Tsurushita et al. (supra). The San11 VH amino acid sequence, including the signal peptide, is shown below. The mature San11 VH sequence starts at position 20 in SEQ ID NO:8.

**[00173]** San11 VH (SEQ ID NO:8):

MKCSWVIVFLMAVVTGVNSEVQLQQSGAELVKPGASVQLSCTASGFNIKDTYMHW  
VKQRPEQGLEWIGRIDPANGDTIYDPNFQGKATITAYTSSNTAYLQLSSLTSEDTVY  
YCARGYYYGSSYWYFDVVGAGTTVTVSS

**[00174]** The San11 VL amino acid sequence, including the signal peptide, is shown below. The mature San11 VL sequence starts at position 21 in SEQ ID NO:9.

**[00175]** San11 VL (SEQ ID NO:9):

MESDTLLLWVLLLWVPGSTGDIVLTQSPASLA VSLGQRATISCRASESVEYYGTGLM  
QWYQQKPGQPPKLLIYSASNVESGVPARFTGSGSGTDFSLNIHPVEEDDIAMYFCQQ  
SRKVPWTFGGGTKLEIKR

**[00176]** The mammalian expression vectors pChSan11-IgG1 and pChSan11-MVIgG1 were constructed by the following procedure. First, the San11 VH gene was constructed as an exon including a splice donor signal at the 3' end of the coding region and the flanking SpeI and HindIII sites. Likewise, the San11 VL gene was constructed as an exon including a splice donor signal and the flanking NheI and EcoRI sites. The SpeI-HindIII fragment carrying the San11 VH exon and the NheI-EcoRI fragment carrying the San11 VL exon were introduced into the corresponding sites of pCh9G6-IgG1, resulting in generation of pChSan11-IgG1. Similarly, the SpeI-HindIII fragment carrying the San11 VH exon and the NheI-EcoRI fragment carrying the San11 VL exon were introduced into the corresponding sites of pCh9G6-MVIgG1, resulting in generation of pChSan11-MVIgG1. The overall structure of pChSan11-IgG1 and pChSan11-MVIgG1 is identical to that of pCh9G6-IgG1 and pCh9G6-MVIgG1 (Fig. 1), respectively. The schematic structure of antibodies produced from pChSan11-IgG1 and pChSan11-MVIgG1 (ChSan11-IgG1 and ChSan11-MVIgG1, respectively) is shown in Fig. 2.

**[00177]** Generation of NS0 stable transfectants producing each of ChSan11-IgG1 and ChSan11-MVIgG1 was performed as described in Example 2. Purification of ChSan11-IgG1 and ChSan11-MVIgG1 by Protein A affinity chromatography was carried out as described in Example 2. SDS-PAGE analysis of ChSan11-IgG1 and ChSan11-MVIgG1 under reducing conditions showed that each antibody was comprised of two chains. By comparing to molecular weight markers, the molecular weight of the light chain was estimated to be 25 kDa for both ChSan11-IgG1 and ChSan11-MVIgG1. The molecular weight of the heavy chain was estimated to be 53 kDa for ChSan11-IgG1 and 79 kDa for ChSan11-MVIgG1. The size of each of the light and heavy chains observed in SDS-PAGE was in agreement with the expected size based on the corresponding amino acid sequence.

**[00178]** The molecular size of native ChSan11-IgG1 and ChSan11-MVIgG1 antibodies was analyzed by gel filtration using a Superose 6 10/300 GL as described in Example 2. Fig. 7 shows the elution patterns of ChSan11-IgG1 and ChSan11-MVIgG1 antibodies. ChSan11-IgG1 had a single dominant peak at 15.7 ml of elution (Fig. 7C). By comparing to the calibration curve with the elution pattern of the molecular weight standards (Gel Filtration Standard, BioRad) (Fig. 7A), the molecular weight of ChSan11-IgG1 in the dominant peak was estimated to be approximately 150 kDa. This corresponds to the predicted molecular weight of a monomer of ChSan11-IgG1 (156 kDa) based on the size of its light and heavy chains on the SDS-PAGE. ChSan11-MVIgG1 had a single dominant peak at 9.9 ml of elution (Fig. 7D). Human monoclonal IgM antibody (Jackson ImmunoResearch) was eluted

at 10.4 ml (Fig. 7B) under the same condition. Considering that the monomer of ChSan11-MVIgG1, which has a molecular weight of roughly 208 kDa based on the SDS-PAGE result, is slightly larger than the monomer of human IgM (approximately 180 kDa), ChSan11-MVIgG1 purified from NS0 cells was concluded to exist as a pentamer or hexamer in the native form.

**[00179]** Cross-linking of CD30 proteins on the cell surface by treatment with a mixture of a monoclonal anti-CD30 IgG antibody and a polyclonal anti-IgG antibody caused cytostasis of the human T cell lymphoma cell line Karpas 299 (Wahl et al., *Cancer Res.* 62:3736-3742, 2002). To investigate the ability of ChSan11-MVIgG1 to cross-link CD30 proteins,  $2 \times 10^5$  Karpas 299 cells were incubated in 0.2 ml of RPMI-1640 media containing 10% FBS in a 96-well plate in the presence of (a) 2  $\mu$ g/ml of ChSan11-IgG1, (b) a mixture of 2  $\mu$ g/ml of ChSan11-IgG1 and 10  $\mu$ g/ml of goat anti-human IgG polyclonal antibody, or (c) 2  $\mu$ g/ml of ChSan11-MVIgG1 (Fig. 8). After a 5 day incubation, Karpas 299 cells were incubated with the tetrazolium salt WST-8 (Dojindo Molecular Technologies, Rockville, MD) and absorbance at 450 nm, which is indicative of dehydrogenase activity and therefore cell viability, was measured. Percent cell viability was calculated by normalizing the absorbance value in the presence of test antibodies to that in the presence of a control IgG antibody that does not bind to Karpas 299 cells. The absorbance value with no cells was used as a background. The viability of Karpas 299 cells was 95% with ChSan11-IgG1, 44% with a mixture of ChSan11-IgG1 and goat anti-human IgG polyclonal antibody (“ChSan11-IgG1 (x-linked)” in the figure), and 48% with ChSan11-MVIgG1 (Figure 8). ChSan11-MVIgG1 induced cytostasis of Karpas 299 cells almost as efficiently as ChSan11-IgG1 cross-linked by goat anti-human IgG polyclonal antibody. ChSan11-MVIgG1 thus functions as a multivalent antibody and cross-links CD30 molecules on the cell surface to induce growth arrest of Karpas 299 cells.

#### **Example 7: Expression of ChSan11-MVIgG1 in HEK293 cells**

**[00180]** IgM forms a pentamer in the presence of J chains, e.g., in the mouse myeloma cell line NS0, while IgM forms a hexamer in the absence of J chains, e.g., in the Chinese hamster ovary cell line CHO (Gilmour et al. *Transfus. Med.* 18:167-174 2008). To investigate the structure in the absence of J chains, ChSan11-MVIgG1 was expressed in the human embryonic kidney cell line HEK293. The pChSan11-MVIgG1 vector was transiently transfected into HEK293 cells using Lipofectamine 2000 (Invitrogen) according to the supplier's protocol. The culture supernatant of transiently transfected HEK293 cells was

fractionated using a Superose 6 gel filtration column following the procedure described in Example 2. The presence of ChSan11-MVIgG1 in each 0.5 ml fraction was monitored by ELISA as described in Example 2. Fig. 9 shows the level of ChSan11-MVIgG1 in each fraction. The highest ELISA signal for ChSan11-MVIgG1 was observed at 9.0 ml of the elution. No significant ELISA signals were detected at the fractions around 16 ml of elution where the monomeric ChSan11-IgG1 antibodies were eluted (Fig. 7C). As a human monoclonal IgM antibody was eluted at 10.4 ml under the same condition, native ChSan11-MVIgG1 is larger than IgM. It was therefore concluded that ChSan11-MVIgG1 was produced as a pentamer or hexamer, or possibly larger than a hexamer, in the absence of J chains.

**Example 8: Generation, expression, purification and characterization of multivalent chimeric anti-DR5 IgG1 antibodies**

**[00181]** The coding region of the VH gene of a mouse anti-human DR5 monoclonal antibody was converted to an exon including a signal peptide-coding sequence, a splice donor signal, and flanking SpeI and HindIII sites. Likewise, the VL gene of the same mouse anti-DR5 monoclonal antibody was converted to an exon including a signal peptide-coding sequence, a splice donor signal, and flanking NheI and EcoRI sites. The SpeI-HindIII fragment carrying the VH exon and the NheI-EcoRI fragment carrying the VL exon of the mouse anti-DR5 monoclonal antibody were introduced to the corresponding sites of pCh9G6-IgG1 to generate pChADR5-IgG1. Similarly, the SpeI-HindIII VH fragment and the NheI-EcoRI VL fragment were introduced into pCh9G6-MVIgG1 to generate pChADR5-MVIgG1. The overall structure of pChADR5-IgG1 and pChADR5-MVIgG1 is identical to that of pCh9G6-IgG1 and pCh9G6-MVIgG1 (Fig. 1), respectively, except that the VH and VL genes are different. The schematic structure of antibodies produced from pChADR5-IgG1 and pChADR5-MVIgG1 (ChADR5-IgG1 and ChADR5-MVIgG1, respectively) is shown in Fig. 2.

**[00182]** Generation of NS0 stable transfectants producing each of ChADR5-IgG1 and ChADR5-MVIgG1 was performed as described in Example 2. Purification of ChADR5-IgG1 and ChADR5-MVIgG1 by Protein A affinity chromatography was carried out with the method described in Example 2. SDS-PAGE analysis of ChADR5-IgG1 and ChADR5-MVIgG1 under reducing conditions showed that each antibody is comprised of two chains: a light chain of the common size between the two antibodies and a heavy chain with a different size for each antibody. By comparing to the location of molecular weight markers on the gel,

the molecular weight of the common light chain was estimated to be 26 kDa. The molecular weight of the heavy chain was estimated to be 51 kDa for ChADR5-IgG1 and 75 kDa for ChADR5-MVIgG1.

**[00183]** The size of native ChADR5-IgG1 and ChADR5-MVIgG1 antibodies was analyzed by gel filtration using a Superose 6 10/300 GL column as described in Example 2. Their elution pattern is shown in Figs. 10A-D. ChADR5-IgG1 had a single dominant peak at 15.9 ml of elution (Fig. 10C). By comparing to the elution pattern of the molecular weight standards (Gel Filtration Standard, BioRad) (Fig. 10A), the molecular weight of ChADR5-IgG1 in the dominant peak was estimated to be approximately 150 kDa. This corresponds to the predicted molecular weight of a monomer of ChADR5-IgG1. ChADR5-MVIgG1 had a single dominant peak at 9.2 ml of elution (Fig. 10D). Since a human IgM monoclonal antibody purified from human myeloma cells (Jackson ImmunoResearch) was eluted at 10.4 ml (Fig. 10B), the molecular size of ChADR5-MVIgG1 is slightly larger than that of human IgM. Considering that a monomer of ChADR5-MVIgG1 is roughly 200 kDa and a monomer of human IgM is approximately 180 kDa, it was concluded that ChADR5-MVIgG1 existed as a pentamer or hexmer in the native form.

**[00184]** Cross-linking of DR5 molecules on the surface induces apoptosis of the human T cell leukemia cell line Jurkat (Guo et al., J. Biol. Chem. 280:41940-41952, 2005). The ability of ChADR5-IgG1 and ChADR5-MVIgG1 to induce apoptosis was assessed by incubation with Jurkat cells. Three sets of test antibodies, (i) ChADR5-IgG1, (ii) ChADR5-IgG1 mixed with ten-fold excess of goat anti-human gamma heavy chain polyclonal antibody for cross-linking, and (iii) ChADR5-MVIgG1, were added at various concentrations starting at 333 ng/ml of final concentration and serial 3-fold dilutions. Cells were incubated in a 96-well plate for 1 day at 37°C in a 7.5% CO<sub>2</sub> incubator. Cell viability was measured using WST-8 reagent (Dojindo). The absorbance value of Jurkat cells without test antibodies was used for 100% viability and the value without cells was used for background. The result is shown in Fig. 11. ChADR5-IgG1 showed no capacity to induce apoptosis. ChADR5-IgG1 cross-linked with 10-fold excess of goat anti-human gamma heavy chain polyclonal antibody (“ChADR5-IgG1 (x-linked)” in the figure) showed approximately 70% cell killing at 111 ng/ml and less than 20% killing at 4 ng/ml. ChADR5-MVIgG1 exhibited a stronger apoptosis-inducing activity, killing more than 90% cells between 333 ng/ml and 1.4 ng/ml. ChADR5-MVIgG1 showed nearly 40% cell killing even at 0.15 ng/ml. ChADR5-MVIgG1 thus functioned as a multivalent antibody and efficiently cross-linked DR5 molecules on the cell surface.

**Example 9: Generation of multivalent anti-CD79a IgG4 antibodies**

**[00185]** The pCh9G6-IgG4 vector for expression of a chimeric anti-CD79a IgG4 monoclonal antibody was constructed by replacing the genomic CH1, hinge, CH2 and CH3 region sequence of the human gamma-1 heavy chain in pCh9G6-IgG1 with a cDNA-derived fragment encoding the CH1, hinge, CH2 and CH3 regions of the human gamma-4 heavy chain (CH1(γ4), h(γ4), CH2(γ4) and CH3(γ4), respectively, in the figure) (Fig. 1). The amino acid sequence of the gamma-4 heavy chain constant region encoded in pCh9G6-IgG4 is shown below.

**[00186]** Heavy chain constant region encoded in pCh9G6-IgG4 (SEQ ID NO:10):

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ASTKGPSVFPLAPCSRSTSESTAALGCLVKDYFPEPVTWSWNSGALTSGVHTFPAVLQ
SSGLYSLSSVVTVPSSSLGTKYTCNVVDHKPSNTKVDKRVESKYGPPCPSCPAPEFLG
GPSVFLFPKPKDTLMISRTPEVTCVVVDVSQEDPEVQFNWYVDGVEVHNAKTKPR
EEQFNSTYRVSVLTVLHQDWLNGKEYKCKVSNKGLPSSIEKTISKAKGQPREPQVY
TLPPSQEEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTPPVLDSDGSFFL
YSRLTVDKSRWQEGNVFCSVSMHEALHNHYTQKSLSLSGK
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**[00187]** The pCh9G6-MVIgG4 vector for expression of a multivalent chimeric anti-CD79a IgG4 monoclonal antibody was constructed by fusing the Cμ3 and Cμ4 regions (SEQ ID NO:5) in frame to the last amino acid of the CH3 region in pCh9G6-IgG4 (Fig. 1). The amino acid sequence of the heavy chain constant region encoded in pCh9G6-MVIgG4 is shown below.

**[00188]** Heavy chain constant region encoded in pCh9G6-MVIgG4 (SEQ ID NO:11):

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ASTKGPSVFPLAPCSRSTSESTAALGCLVKDYFPEPVTWSWNSGALTSGVHTFPAVLQ
SSGLYSLSSVVTVPSSSLGTKYTCNVVDHKPSNTKVDKRVESKYGPPCPSCPAPEFLG
GPSVFLFPKPKDTLMISRTPEVTCVVVDVSQEDPEVQFNWYVDGVEVHNAKTKPR
EEQFNSTYRVSVLTVLHQDWLNGKEYKCKVSNKGLPSSIEKTISKAKGQPREPQVY
TLPPSQEEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTPPVLDSDGSFFL
YSRLTVDKSRWQEGNVFCSVSMHEALHNHYTQKSLSLSGKDQDTAIRVFAIPPSFA
SIFLTKSTKLTCVTDLTTYDSVTISWTRQNGEAVKTHTNISESHPNATFSAVGEASIC
EDDWNSGERFTCTVHTDLPPLQQTISRPKGVALHRPDVYLLPPAREQLNLRESATI
TCLVTGFSPADVFVQWMQRGQPLSPEKYVTSAPMPEPQAPGRYFAHSILTVSEEEWN
TGETYTCVVAHEALPNRVTERTVDKSTGKPTLYNVSLVMSDTAGTCY
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**[00189]** Generation of NS0 stable transfecants producing Ch9G6-MVIgG4 was performed as described in Example 2. Purification of Ch9G6-MVIgG4 by Protein A affinity

chromatography was carried out with the method described in Example 2. SDS-PAGE analysis under reducing conditions showed that Ch9G6-MVIgG4 is comprised of an approximately 25 kDa light chain and an approximately 78 kDa heavy chain.

**[00190]** The molecular size of native Ch9G6-MVIgG4 was analyzed by gel filtration using a Superose 6 10/300 GL column as described in Example 2. One major peak (at 10.1 ml of elution) and one minor peak (at 14.1 ml of elution) were observed in the elution pattern of Ch9G6-MVIgG4 (Fig. 12C). By comparing to the elution pattern of BioRad's molecular weight standards (Fig. 12A) and human IgM (eluted at 10.4 ml; Fig. 12B), and considering the expected size of monomeric Ch9G6-MVIgG4 (~208 kDa) and IgM (~180 kDa), it was concluded that Ch9G6-MVIgG4 eluted at 10.1 ml was a pentamer or hexamer. Such multimeric Ch9G6-MVIgG4 constituted 83% of the total purified antibodies.

**Example 10: Expression, purification and characterization of multivalent IgG3 antibodies**

**[00191]** Three vectors were constructed for expression of a chimeric anti-CD79a IgG3 monoclonal antibody and its two derivatives. The pCh9G6-IgG3D vector was constructed by replacing the HindIII-EagI fragment carrying the genomic CH1, hinge, CH2 and CH3 regions of the human gamma-1 heavy chain in pCh9G6-IgG1 with the HindIII-EagI fragment carrying the genomic CH1, fourth hinge, CH2 and CH3 regions of the human gamma-3 heavy chain (CH1( $\gamma$ 3), h( $\gamma$ 3), CH2( $\gamma$ 3) and CH3( $\gamma$ 3), respectively, in the figure) (Fig. 1). The coding sequence of the first, second and third hinge regions was eliminated in pCh9G6-IgG3D. The amino acid sequence of the heavy chain constant region encoded in pCh9G6-IgG3D is shown below.

**[00192]** Heavy chain constant region encoded in pCh9G6-IgG3D (SEQ ID NO:12):  
ASTKGPSVFPLAPCSRSTSGGTAALGCLVKDYFPEPVTWNSGALTSGVHTFPAVL  
QSSGLYSLSSVVTVPSSSLGTQTYTCNVNHKPSNTKVDKRVEPKSCDTPPPCPRCPAP  
ELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVQFKWYVDGVEVHNAK  
TKPREEQYNSTFRVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKKGQPRE  
PQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESSGQPENNYNTTPMLSDG  
SFFLYSKLTVDKSRWQQGNIFSCSVMHEALHNRFTQKSLSSLSPGK

**[00193]** The pCh9G6-IgG3D/M vector was constructed by fusing the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain (SEQ ID NO:5) in frame to the last amino acid of the hinge region in pCh9G6-IgG3D (Fig. 1). The CH2 and CH3 exons of the human gamma-3 heavy chain were removed in pCh9G6-IgG3D/M. The structure of the resultant heavy chain

constant region encoded in pCh9G6-IgG3D/M, which is composed of, from the N-terminus to the C-terminus, the CH1 and fourth hinge regions of the human gamma-3 heavy chain and the CH3 and CH4 regions of the human  $\mu$  heavy chain, is identical to the heavy chain constant region of IgG-C $\mu$ 3-C $\mu$ 4 reported by Sorensen et al. (Int. Immunol. 12:19-27 2000). The amino acid sequence of the heavy chain constant region encoded in pCh9G6-IgG3D/M is shown below.

**[00194]** Heavy chain constant region encoded in pCh9G6-IgG3D/M (SEQ ID NO:13):  
ASTKGPSVFPLAPCSRSTSGGTAALGCLVKDYFPEPVTWSWNSGALTSGVHTFPAVL  
QSSGLYSLSSVVTVPSSSLGTQTYTCNVNHKPSNTKVDKRVEPKSCDTPPPCCRCPDQ  
DTAIRVFAIPPSFASIFLTKSTKLTCLVTDLTTYDSVTISWTRQNGEAVKTHTNISESHP  
NATFSAVGEASICEDDWNSGERFTCTVTHDLPSPLKQTISRPKGVALHRPDVYLLPP  
AREQLNLRESATITCLVTGFSPADVFVQWMQRGQPLSPEKYVTSAPMPEPQAPGRYF  
AHSILTVSEEEWNTGETYTCVVAHEALPNRVTERTVDKSTGKPTLYNVSLVMSDTA  
GTCY

**[00195]** The pCh9G6-MVIgG3D vector was constructed by fusing the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain (SEQ ID NO:5) in frame to the last amino acid of the CH3 exon of the human gamma-3 heavy chain in pCh9G6-IgG3D (Fig. 1). The amino acid sequence of the resulting heavy chain constant region encoded in pCh9G6-MVIgG3D is shown below.

**[00196]** Heavy chain constant region encoded in pCh9G6-MVIgG3D (SEQ ID NO:14):  
ASTKGPSVFPLAPCSRSTSGGTAALGCLVKDYFPEPVTWSWNSGALTSGVHTFPAVL  
QSSGLYSLSSVVTVPSSSLGTQTYTCNVNHKPSNTKVDKRVEPKSCDTPPPCCRCPAP  
ELLGGPSVFLFPPPKDLMISRTPEVTCVVVDVSHEDPEVQFKWYVDGVEVHNAK  
TKPREEQYNSTFRVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKKGQPRE  
PQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESSGQPENNYNTTPMLDSDG  
SFFLYSKLTVDKSRWQQGNIFSCSVMHEALHNRTQKSLSLSPGKDQDTAIRVFAIPP  
SFASIFLTKSTKLTCLVTDLTTYDSVTISWTRQNGEAVKTHTNISESHPNATFSAVGEA  
SICEDDWNSGERFTCTVTHDLPSPLKQTISRPKGVALHRPDVYLLPPAREQLNLRES  
ATITCLVTGFSPADVFVQWMQRGQPLSPEKYVTSAPMPEPQAPGRYFAHSILTVSEEE  
WNTGETYTCVVAHEALPNRVTERTVDKSTGKPTLYNVSLVMSDTAGTCY

**[00197]** The schematic structure of the monomer form of the antibodies produced from pCh9G6-IgG3D, pCh9G6-IgG3D/M and pCh9G6-MVIgG3D (Ch9G6-IgG3D, Ch9G6-IgG3D/M and Ch9G6-MVIgG3D, respectively) is shown in Fig. 2.

**[00198]** Generation of NS0 stable transfectants producing each of Ch9G6-IgG3D, Ch9G6-IgG3D/M and Ch9G6-MVIgG3D antibodies was carried out as outlined in Example 2. NS0 stable transfectants producing a high level of Ch9G6-IgG3D, Ch9G6-IgG3D/M and Ch9G6-MVIgG3D antibodies were adapted to growth in serum-free media using Hybridoma SFM and expanded into a roller bottle as described in Example 2. After centrifugation and filtration, culture supernatant was loaded onto a Protein G Sepharose column (GE Healthcare) for Ch9G6-IgG3D and Ch9G6-MVIgG3D. The Protein G Sepharose column was washed with PBS before the antibody was eluted with 0.1 M glycine-HCl (pH 2.5). After neutralization with 1 M Tris-HCl (pH 8), the buffer of eluted antibody was changed to PBS by dialysis.

**[00199]** Since Ch9G6-IgG3D/M, which lacks the CH2 and CH3 regions of the human gamma-3 heavy chain, did not bind to Protein G, culture supernatant of NS0 stable transfectants producing Ch9G6-IgG3D/M was loaded onto a goat anti-human IgM agarose column (Sigma). The anti-human IgM agarose column was washed with PBS before the antibody was eluted with 0.1 M glycine-HCl (pH 2.5). After neutralization with 1 M Tris-HCl (pH 8), the buffer of eluted antibody was changed to PBS by dialysis.

**[00200]** Purified antibodies were characterized by SDS-PAGE according to standard procedures. Analysis under reducing conditions indicated that each of Ch9G6-IgG3D, Ch9G6-IgG3D/M and Ch9G6-MVIgG3D antibodies is comprised of two chains. The molecular weight of each chain was estimated by comparing the mobility on the gel to that of molecular weight markers. The light chain, which is common among Ch9G6-IgG3D, Ch9G6-IgG3D/M and Ch9G6-MVIgG3D, had a molecular weight of approximately 25 kDa. The molecular weight of the heavy chain was estimated to be 53 kDa for Ch9G6-IgG3D, 60 kDa for Ch9G6-IgG3D/M, and 81 kDa for Ch9G6-MVIgG3D. The estimated size of each of the light and heavy chains is in agreement with the size expected based on the corresponding amino acid sequence.

**[00201]** The size of Ch9G6-IgG3D, Ch9G6-IgG3D/M and Ch9G6-MVIgG3D antibodies in the native form was analyzed by gel filtration using the AKTA Basic FPLC system with a Superose 6 10/300 GL column as described in Example 2. Fig.13 shows the elution patterns of Ch9G6-IgG3D (Fig. 13C), Ch9G6-IgG3D/M (Fig. 13D) and Ch9G6-MVIgG3D (Fig. 13E). A single dominant peak was observed with Ch9G6-IgG3D at 15.6 ml in the elution. By comparing to the elution pattern of Gel Filtration Standard (BioRad) (Fig. 13A), the molecular weight of Ch9G6-IgG3D in the dominant peak was estimated to be approximately

150 kDa, which corresponds to the predicted molecular weight of a monomer of Ch9G6-IgG3D from the SDS-PAGE result.

**[00202]** Four major peaks were observed with Ch9G6-IgG3D/M (Figure 13D). The molecular weight of Ch9G6-IgG3D/M eluted at 12.3 ml, 15.0 ml and 16.1 ml was estimated to be 650kDa, 180kDa and 90 kDa, respectively. Proteins in the fourth major peak eluted at 20.8 ml, which were estimated to have a molecular weight of roughly 2 kDa, are likely to be degradation products of Ch9G6-IgG3D/M that bound to and eluted from the anti-IgM agarose column.

**[00203]** A single dominant peak was observed with Ch9G6-MVIgG3D at 10.4 ml in the elution (Fig. 13E). Human IgM was also eluted at 10.4 ml (Fig. 13B). Considering the size of a monomer of Ch9G6-MVIgG3D (~200 kDa) and IgM (~180 kDa) estimated from the SDS-PAGE result, it was concluded that Ch9G6-MVIgG3D was produced as a pentamer or hexamer in the native form.

#### **Example 11: Binding of multivalent IgG3 antibodies to FcRn**

**[00204]** The ability of Ch9G6-IgG3D, Ch9G6-IgG3D/M and Ch9G6-MVIgG3D antibodies to bind to FcRn in a pH-dependent manner was analyzed by flow cytometry using NS0 cells expressing human FcRn on the cell surface (NS0/FcRn cells). Ch9G6-IgG3D, Ch9G6-IgG3D/M and Ch9G6-MVIgG3D at 1  $\mu$ g/ml were separately incubated with NS0/FcRn cells at pH 6.0 and 7.5 at the primary staining step as described in Example 4. Antibodies binding to FcRn were detected using PE-labeled goat polyclonal anti-human gamma chain antibody (for Ch9G6-IgG3D and no antibody control) or PE-labeled goat polyclonal anti-human  $\mu$  chain antibody (for Ch9G6-IgG3D/M, Ch9G6-MVIgG3D and no antibody control) at the secondary staining step. As shown in Fig. 14, Ch9G6-IgG3D bound strongly to FcRn at pH 6.0 and only weakly at pH 7.5. Similarly, Ch9G6-MVIgG3D bound strongly to FcRn at pH 6.0. FcRn binding of Ch9G6-MVIgG1 was much stronger at pH 6.0 than at pH 7.5. Thus, both Ch9G6-IgG3D and Ch9G6-MVIgG3D exhibited pH-dependent binding to FcRn, indicating these antibodies have a long serum half-life. Ch9G6-IgG3D/M did not show any significant binding to FcRn at pH 6.0 or 7.5, indicating a short serum half-life of Ch9G6-IgG3D/M. This is consistent with the fact that Ch9G6-IgG3D/M lacks the binding site to FcRn.

**Example 12: Binding of multivalent IgG3 antibodies to CD16**

**[00205]** Binding of multivalent IgG3 antibodies to human CD16 was analyzed by flow cytometry. HEK293 cells transiently expressing human CD16 on the surface were incubated with 1  $\mu$ g/ml of Ch9G6-IgG3D, Ch9G6-IgG3D/M or Ch9G6-MVIgG3D in FACS Buffer (PBS containing 0.5% bovine serum albumin and 0.025% sodium azide) for 30 min on ice. As a control, HEK293 cells expressing human CD16 were also incubated without test antibodies. After washing with FACS buffer, cells were incubated with PE-labeled goat polyclonal anti-human gamma heavy chain antibody (for Ch9G6-IgG3D, Ch9G6-MVIgG3D and no antibody control) or PE-labeled goat polyclonal anti-human  $\mu$  heavy chain antibody (for Ch9G6-IgG3D/M, Ch9G6-MVIgG3D and no antibody control) in FACS buffer at the secondary staining step for 15 min on ice. After washing with FACS buffer, stained cells were analyzed by flow cytometry.

**[00206]** Ch9G6-IgG3D showed a strong binding to human CD16 (Fig. 15D). Ch9G6-MVIgG1 showed even a stronger CD16 binding than Ch9G6-IgG3D did (Fig. 15F), indicating the capability of exerting ADCC. On the other hand, Ch9G6-IgG1/M showed very weak binding, if any, to human CD16 (Fig. 15E) when compared the cells stained with PE-labeled goat anti- $\mu$  heavy chain antibody alone (Fig. 15C), indicating that Ch9G6-IgG1/M has no ADCC activity. The insignificant binding of Ch9G6-IgG3D/M to CD16 is not due to the difference of PE-labeled secondary antibodies because strong CD16 binding of Ch9G6-MVIgG3D was observed when PE-labeled goat anti- $\mu$  heavy chain antibody was used at the secondary staining step (Fig. 15G). The inability of Ch9G6-IgG3D/M to bind to CD16 is consistent with the fact that Ch9G6-IgG3D/M lacks the CH2 and CH3 regions of the human gamma-3 heavy chain.

**[00207]** For generation of multivalent IgG2 antibodies, the last amino acid of the CH3 exon of the human gamma-2 heavy chain is fused in frame to the CH3 and CH4 regions of the human  $\mu$  heavy chain. The resulting heavy chain is composed, from the N-terminus to the C-terminus, (i) the CH1, hinge and CH2 and CH3 regions of the human gamma-2 heavy chain, and then (ii) the CH3 and CH4 regions of the human  $\mu$  heavy chain. The resulting multivalent IgG2 antibody is expressed in mammalian cells, such as NS0, CHO or HEK293 cells, purified from spent culture supernatant using a Protein A affinity column, and characterized with gel filtration and SDS-PAGE.

**Example 13: Multivalent IgG2 antibodies:**

**[00208]** For generation of multivalent IgG2 antibodies, the last amino acid of the CH3 exon of the human gamma-2 heavy chain is fused in frame to the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain. The resulting heavy chain is composed, from the N-terminus to the C-terminus, (i) the CH1, hinge and CH2 and CH3 regions of the human gamma-2 heavy chain, and then (ii) the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain. The resulting multivalent IgG2 antibody is expressed in mammalian cells, such as NS0, CHO or HEK293 cells, purified from spent culture supernatant using a Protein A affinity column, and characterized with gel filtration and SDS-PAGE.

**Example 14: Multivalent IgA antibodies:**

**[00209]** For generation of multivalent IgA antibodies, the last amino acid of the CH3 exon of the human alpha-1 or alpha-2 heavy chain is fused in frame to the CH3 and CH4 regions of the human  $\mu$  heavy chain. The resulting heavy chain is composed, from the N-terminus to the C-terminus, (i) the CH1, CH2 and CH3 regions of the human alpha-1 or alpha-2 heavy chain, and then (ii) the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain. The resulting multivalent IgA antibody is expressed in mammalian cells, such as NS0, CHO or HEK293 cells, purified from culture supernatant of using a Jacalin lectin column or other standard procedures, and characterized with gel filtration and SDS-PAGE.

**Example 15: Multivalent Fc fusion proteins**

**[00210]** The technology invented in this work to generate multivalent IgG antibodies is also applicable to generation of multivalent Fc fusion proteins. For example, the pCh9G6-MVIgG1 vector is modified in such a way that (i) the VH and CH1 exons are removed, (ii) a cDNA-derived fragment encoding the signal peptide and extracellular region of human TRAIL (TRAIL EC) is fused in frame to the first amino acid of the hinge exon, and (iii) the light chain transcription unit is eliminated. A flexible polypeptide linker, such as Thr-Gly-Gly-Gly, may be placed between TRAIL and the hinge region. The resulting Fc fusion protein (TRAIL-MVFc) is composed of, from the N-terminus to the C-terminus, (i) TRAIL EC, (ii) the hinge, CH2 and CH3 regions of the human gamma-1 heavy chain, and then (iii) the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain. Such Fc fusion proteins are produced as a pentamer or hexamer in mammalian cells. The biological activity of such multimeric Fc fusion proteins to induce apoptosis of cells expressing DR4 or DR5 is analyzed by standard procedures.

**Example 16: Multispecific Fc fusion proteins**

**[00211]** The technology for production of multivalent Fc fusion proteins is further applicable to generation of multispecific Fc fusion proteins. For example, three vectors are constructed for expression of three different Fc fusion proteins. The first expression vector encodes the extracellular region of human TNF receptor type II (TNFR-II EC) fused to the hinge, CH2 and CH3 regions of the human gamma-1 heavy chain, which is further fused to the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain (TNFR-II-MVFc). The second vector encodes the extracellular region of human LFA-3 fused to the hinge, CH2 and CH3 regions of the human gamma-1 heavy chain, which is further fused to the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain (LFA-3-MVFc). The third vector encodes the extracellular region of human IL-1 receptor fused to the hinge, CH2 and CH3 regions of the human gamma-1 heavy chain, which is further fused to the C $\mu$ 3 and C $\mu$ 4 regions of the human  $\mu$  heavy chain (IL-1R-MVFc). TNFR-II-MVFc, LFA-3-MVFc and IL-1R-MVFc are expressed simultaneously to generate multivalent Fc fusion proteins that are capable of binding to TNF $\alpha$ , CD2 (a receptor of LFA-3), and IL-1. The efficacy of such multispecific, multivalent Fc fusion proteins to treat inflammatory diseases is studied using standard methods.

**Example 17: Multivalent proteins composed of IgG antibodies and Fc fusion proteins**

**[00212]** The technology for production of multivalent IgG antibodies and Fc fusion proteins is also applicable for generation of multivalent proteins composed of both IgG antibodies and Fc fusion proteins. For example, mammalian cells are cotransfected with two expression vectors: (i) an expression vector for production of multivalent anti-DR5 IgG antibodies, and (ii) an expression vector for production of multivalent TRAIL-Fc fusion proteins. The expressed multimeric proteins are composed of both anti-DR5 IgG antibodies and TRAIL-Fc fusion proteins. The biological activity of such proteins to induce DR4- and DR5-mediated apoptosis is analyzed by standard procedures.

**Example 18: Bispecific multivalent antibody**

**[00213]** The vectors pCh9G6-MVIgG1 and pChSan11-MVIgG1, which express multivalent IgG1 antibodies binding to human CD79a and CD30, respectively, were either individually or together transfected into HEK293 cells using Lipofectamine 2000 (Invitrogen) according to the supplier's protocol. HEK293 cells were then incubated in DME medium containing 10% FBS for 4 days at 37°C in a 7.5% CO<sub>2</sub> incubator. Antigen binding of

transiently expressed antibodies in culture supernatants was tested with the following two formats of ELISA.

**[00214]** In the first format of ELISA, wells of a microtiter plate were coated with recombinant human CD30 extracellular region fused at the C-terminus to the Fc region of human  $\gamma 1$  chain (CD30-Fc; SEQ ID NO:37). After blocking the wells with Block Buffer, appropriately diluted culture supernatants of HEK293 cells were applied to the wells and incubated overnight at 4°C. After washing wells with Wash Buffer, recombinant human CD79a extracellular region fused at the C-terminus to the human  $\lambda 2$  constant region (CD79a-C $\lambda$ ; SEQ ID NO:38) in ELISA Buffer was applied to the wells. A cysteine residue at the second location from the carboxyl terminal in the human  $\lambda 2$  constant region was changed to a serine residue in CD79a-C $\lambda$ . After incubating the ELISA plate for 1 hr at room temperature and washing the wells with Wash Buffer, bound CD79a-C $\lambda$  was detected by HRP-conjugated goat anti-human  $\lambda$  chain polyclonal antibody. Color development was initiated by adding ABTS substrate and stopped with 2% oxalic acid. Absorbance was read at 405 nm.

**[00215]** Culture supernatants of HEK293 cells transfected with either pCh9G6-MVIgG1 or pChSan11-MVIgG1 showed no signal in this first format of ELISA when compared to the culture supernatant of untransfected HEK293 cells. When pCh9G6-MVIgG1 and pChSan11-MVIgG1 were cotransfected into HEK293 cells, the culture supernatant showed a strong signal in this format of ELISA, indicating the presence of bispecific antibodies that can bind simultaneously to CD79a- C $\lambda$  in solution and CD30-Fc coated on the ELISA plate.

**[00216]** In the second format of ELISA, wells of a microtiter plate were coated with recombinant human CD79a extracellular region fused at the C-terminus to the Fc region of human  $\gamma 1$  chain (CD79a-Fc; SEQ ID NO:39). After blocking the wells with Block Buffer, appropriately diluted culture supernatants of HEK293 cells were applied to the wells and incubated overnight at 4°C. After washing wells with Wash Buffer, recombinant human CD30 extracellular region fused at the C-terminus to the human  $\lambda 2$  constant region (CD30-C $\lambda$ ; SEQ ID NO:40) in ELISA Buffer was applied to the wells. A cysteine residue at the second location from the carboxyl terminal in the human  $\lambda 2$  constant region was changed to a serine residue in CD30-C $\lambda$ . After incubating the ELISA plate for 1 hr at room temperature and washing the wells with Wash Buffer, bound CD30-C $\lambda$  was detected by HRP-conjugated goat anti-human  $\lambda$  chain polyclonal antibody. Color development was initiated by adding ABTS substrate and stopped with 2% oxalic acid. Absorbance was read at 405 nm.

**[00217]** Culture supernatants of HEK293 cells transfected with either pCh9G6-MVIgG1 or pChSan11-MVIgG1 showed no signal in this second format of ELISA when compared to

the culture supernatant of untransfected HEK293 cells. On the other hand, the culture supernatant of HEK293 cells cotransfected with pCh9G6-MVIgG1 and pChSan11-MVIgG1 showed a strong signal in the second format of ELISA, confirming the presence of bispecific antibodies that can bind to both CD79a and CD30.

**[00218]** The amino acid sequence of the recombinant human CD30 extracellular region fused at the C-terminus to the Fc region of human gamma-1 chain (CD30-Fc) is:

FPQDRPFEDTCHGNPSHYDKAVRRCCYRCMGLFPTQQCPQRPTDCRKQCEPDYY  
LDEADRCTACVTCRDDLVEKTPCAWNSSRVCECRPGMFCSTSAVNASCARCFHHSV  
CPAGMIVKFPGTAQKNTVCEPASPGVSPACASPENCKEPSSGTIPQAKPTPVSPATSSA  
STMPVRGGTRLAQEAASKLTRAPDSPSSVGRPSSDPGLSPTQPCPEGSGDCRKQCEPD  
YYLDEAGRCTACVSCSRDDLVEKTPCAWNSSRTCECRPGMICATSATNSCARCVPY  
PICAAETVTKPQDMAEKDTTAEAPPLGTQPDCNPTPENGEAPASTSPTQSLLVDSQAS  
KTLPIPTSAPVALSSTGKPVLDTGGGEPKSCDKTHTCPPCPAPELLGGPSVFLPPKPK  
DTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTPREEQYNSTYRVVS  
VLTVLHQDWLNGKEYKCKVSNKALPAPIEKTIASKAKGQPREPQVYTLPPSRDELT  
QVSLTCLVKGFYPSDIAVEWESNGQPENNYKTPVLDSDGSFFLYSKLTVDKSRWQ  
QGNVFSCSVMHEALHNHYTQKSLSLSPGK (SEQ ID NO:37).

**[00219]** The amino acid sequence of the recombinant human CD79a extracellular region fused at the C-terminus to the human  $\lambda$ 2 constant region (CD79a- $\lambda$ ) is:

ALWMHKVPASLMVSLGEDAHFQCPHNSSNNANVTWWRVLHGNYTWPPEFLGPGE  
DPNGTLIIQNVNPKSHGGIYVCRVQEGNESYQQSCGTYLVRQPPPRPFLDMGEGT  
RTGGGGQPKAAPSVTLFPPSSEELQANKATLVCLISDFYPGAVTVAWKADSSPVKAG  
VETTPSKQSNNKYAASSYLSLTPEQWKSHRSYSCQVTHEGSTVEKTVAPTESS (SEQ  
ID NO:38).

**[00220]** The amino acid sequence of the recombinant human CD79a extracellular region fused at the C-terminus to the Fc region of human gamma-1 chain (CD79a-Fc) is:

ALWMHKVPASLMVSLGEDAHFQCPHNSSNNANVTWWRVLHGNYTWPPEFLGPGE  
DPNGTLIIQNVNPKSHGGIYVCRVQEGNESYQQSCGTYLVRQPPPRPFLDMGEGT  
RTGGGEPKSCDKTHTCPPCPAPELLGGPSVFLPPKPKDTLMISRTPEVTCVVVDVSH  
EDPEVKFNWYVDGVEVHNAKTPREEQYNSTYRVSVLTVLHQDWLNGKEYKCK  
VSNKALPAPIEKTIASKAKGQPREPQVYTLPPSRDELT  
QVSLTCLVKGFYPSDIAVE  
WESNGQPENNYKTPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHN  
YTQKSLSLSPGK (SEQ ID NO:39).

**[00221]** The amino acid sequence of the recombinant human CD30 extracellular region fused at the C-terminus to the human  $\lambda$ 2 constant region (CD30- $\lambda$ ) is:

FPQDRPFEDTCHGNPSHYYDKAVRRCCYRCMGLFPTQQCPQRPTDCRKQCEPDYY  
LDEADRCTACVTCSRDDLVEKTPCAWNSSRVCECRPGMFCSTSAVNSCARcffHSV  
CPAGMIVKFPGTAQKNTVCEPASPGVSPACASPenCKEPSSGTIPQAKPTPVSPATSSA  
STMPVRGGTRLAQEAASKLTRAPDSPSSVGRPSSDPGLSPTQPCPEGSGDCRKQCEPD  
YYLDEAGRCTACVSCSRDDLVEKTPCAWNSSRTCECRPGMICATSATNSCARCVPY  
PICAAETVTKPQDMAEKDTTFeAPPLGTQPDNCNPTPENGEAPASTSPTQSLLVDSQAS  
KTLPIPTSAPVALSSTGKPVLDTGGGGQPKAAPSVTLFPPSSEELQANKATLVCLISDF  
YPGAVTVAWKADSSPVKAGVETTPSKQSNNKYAASSYLSLTPEQWKSHRSYSCQV  
THEGSTVEKTVAPTESS (SEQ ID NO:40).

**Example 19: Therapeutic efficacy of the multimeric anti-DR4 IgG antibody in a mouse systemic xenograft model with Ramos cells**

**[00222]** The mouse hybridoma producing the anti-human death receptor 4 (DR4; also called Apo2, TRAIL receptor 1 and TNFRSF10A) monoclonal IgG1/lambda antibody YON007 was generated at JN Biosciences (Mountain View, CA) using the extracellular region of human DR4 fused to the Fc region of human gamma-1 heavy chain (DR4-Fc) (SEQ ID NO:41) as an immunogen and following standard hybridoma techniques.

**[00223]** The amino acid sequence of YON007 VH and VL was determined by standard experimental procedures such as the method described by Tsurushita et al. (supra). The amino acid sequence of YON007 VH, including the signal peptide sequence, is MNRLTSSLILLIVPAYVLSQVTLKESGPGILQPSQTLCSFSGFSLSTSGMGVSWIR QPSGKGLEWLAHIYWDDDKNRKNPSLKSRLKISKDTSSNQVFLKITSVDTADTATYYC TRRGEYGNFDYWGQGTTLVSS (SEQ ID NO:42) (US 61/679,045). The mature YON007 VH starts at position 20 in SEQ ID NO:42. The amino acid sequence of YON007 VL, including the signal peptide sequence, is

MAWISLILSLLALSSGAISQAVVTQESALTSPGETVTLTCRSSSGAVTTSNFANWVQ EKPDHLFTGLIGGTNNRAPGVPARFSGSLIGDKAALTITGAQTEDEAIYFCALWYSNH WVFGGGTKLTVL (SEQ ID NO:43) (US 61/679,045). The mature YON007 VL starts at position 20 in SEQ ID NO:43.

**[00224]** Humanization of YON007 VH and VL was carried out by the procedure described by Tsurushita et al. (supra). The amino acid sequence of humanized YON007 (HuYON007) VH, including the signal peptide, is

MNRLTSSL LLLIVPAYVLSQVTLRESGPALVKPTQTLTLTCTFSGFSLSTSGMGVSWI RQPPGKALEWLAHIYWDDD KRYNPSLKSRLTISKDTSKNQVVLMTNMDPVDTATY YCTRRGEYGNFDYWGQGTLVTVSS (SEQ ID NO:44) (US 61/679,045). The mature HuYON007 VH sequence starts at position 20 in SEQ ID NO:44.

**[00225]** The amino acid sequence of humanized YON007 (HuYON007) VL is MAWISLILSLLALSSGAISQTVVTQEPFSVSPGGTVTLTCRSSSGAVTTSNFANWVQ QTPGQAPRGLIGGTNNRAPGVPDFSGSLLGNKAALTITGAQADDES DYYCALWYS NHWVFGGGTKLTVL (SEQ ID NO:45) (US 61/679,045). The mature HuYON007 VL sequence starts at position 20 in SEQ ID NO:45.

**[00226]** A gene encoding HuYON007 VH (SEQ ID NO:46) was synthesized as an exon including a splice donor signal at the 3' end of the coding region, an SpeI site at the 5' end of the fragment, and a HindIII site at the 3' end of the fragment. A gene encoding HuYON007 VL (SEQ ID NO:47) was synthesized as an exon including a splice donor signal at the 3' end of the coding region, a NheI site at the 5' end of the fragment, and an EcoRI site at the 3' end of the fragment.

**[00227]** The structure of the mammalian expression vector pHuYON007 for production of a humanized anti-human DR4 monoclonal IgG1/lambda antibody, HuYON007-IgG1, is essentially identical to the structure of pCh9G6-IgG1 (Fig. 1) except that (1) the 9G6 VH gene was replaced with the HuYON007 VH gene (SEQ ID NO:46) between the SpeI and HindIII sites, (2) the 9G6 VL gene was replaced with the HuYON007 VL gene (SEQ ID NO:47) between the NheI and EcoRI sites, (3) the C $\kappa$ -coding exon was replaced with the exon encoding the human lambda-2 constant region, and (4) the gpt gene was replaced with the puromycin N-acetyl-transferase gene.

**[00228]** The amino acid sequence of the mature heavy chain encoded in pHuYON007 is QVTLRESGPALVKPTQTLTLTCTFSGFSLSTSGMGVSWIRQPPGKALEWLAHIYWDD DKRYNPSLKSRLTISKDTSKNQVVLMTNMDPVDTATYYCTRRGEYGNFDYWGQG TLTVSSASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTVSWNSGALTSGV HTFPAVLQSSGLYSLSSVTVPSQLGTQTYICNVNHKPSNTKVDKKVEPKSCDKTHT CPPCPAPELLGGPSVFLFPPPKDLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGV EVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKISK AKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTP PVLDSDGSFFLYSKLTVDKSRWQQGVFSCSVMHEALHNHYTQKSLSLSPGK (SEQ ID NO:48).

**[00229]** The amino acid sequence of the mature light chain encoded in pHuYON007 is QTVVTQEPEFSVSPGGTVTLCRSSSGAVITSNFANWVQQTPGQAPRGLIGGTNNRA PGVPDRFSGSILGNKAALTITGAQADDESDYYCALWYSNHWFGGGKLTVLGQPK AAPSVTLFPPSSEELQANKATLVCLISDFYPGAVTVAWKADSSPVKAGVETTPSKQS NNKYAASSYLSLTPEQWKSHRSYSCQVTHEGSTVEKTVAPTECS (SEQ ID NO:49).

**[00230]** For expression of multimeric HuYON007 IgG antibodies, the coding region of C $\mu$ 3 and C $\mu$ 4 was fused in frame to the last amino acid of the CH3 exon in pHuYON007. The light chain sequence was not modified. The amino acid sequence of the mature heavy chain encoded in the resultant plasmid, pHuYON007-MVIgG1, is

QVTLRESGPALVKPTQTLTLTCTFSGFSLSTSGMGVSWIRQPPGKALEWLAHIYWDD DKRYNPSLKSRLTISKDTSKNQVVLMTNMDPVDTATYYCTRRGEYGNFDYWGQG TLTVVSSASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTWSWNSGALTSGV HTFPAVLQSSGLYSLSSVVTVPSSLGTQTYICNVNHKPSNTKVDKKVEPKSCDKTHT CPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGV EVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISK AKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTP PVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGKDQDT AIRVFAIPPSFASIFLTKSTKLTCLVTDLTTYDSVTISWTRQNGEAVKTHTNISEHPNA TFSAVGEASICEDDWNSGERFTCTVHTDLPSPLKQTISRPKGVALHRPDVYLLPPAR EQLNLRESATITCLVTGFSPADVFVQWMQRGQPLSPEKYVTSAPMPEPQAPGRYFAH SILTVSEEEWNTGETYTCVVAHEALPNRVTERTVDKSTGKPTLYNVSLVMSDTAGTC Y (SEQ ID NO:50).

**[00231]** The expression vectors pHuYON007 and pHuYON007-MVIgG1 were individually introduced into the chromosome of a Chinese hamster ovary cell line CHO-S (Invitrogen) to obtain cell lines stably producing humanized IgG1/lambda antibodies HuYON007-IgG1 and HuYON007-MVIgG1, respectively. CHO-S cells were grown in SFM4CHO media (HyClone) at 37°C in a 7.5% CO<sub>2</sub> incubator. Stable transfection into CHO-S was carried out by electroporation. Before transfection, each expression vector was linearized using FspI. In a typical experiment, approximately 10<sup>7</sup> cells were transfected with 20  $\mu$ g of linearized plasmid, suspended in SFM4CHO, and plated into several 96-well plates after appropriate dilutions of cells. After 48 hr, puromycin was added for selection of stable transfectants. Approximately two weeks after the initiation of selection, culture supernatants of transfectants were assayed for antibody production. Expression of antibodies was measured by sandwich ELISA using goat anti-human gamma heavy chain polyclonal

antibody for coating and HRP-conjugated goat anti-human lambda chain antibody for detection of bound HuYON007-IgG1 or HuYON007-MVIgG1 antibody. CHO-S stable transfectants producing each of HuYON007-IgG1 and HuYON007-MVIgG1 were expanded in SFM4CHO.

**[00232]** After centrifugation and filtration, culture supernatants were loaded onto a Protein A column (HiTrap MABSelect SuRe, GE Healthcare, Piscataway, NJ). The column was washed with PBS before the antibody was eluted with 0.1 M glycine-HCl (pH 3.0). Buffer of all eluted antibodies was neutralized with 1 M Tris-HCl (pH 8) and then changed to PBS by dialysis. In the gel filtration analysis using a Superose 6 10/300 GL as described above, a single dominant peak corresponding to approximately 150 kDa was observed for HuYON007-IgG1. A single dominant peak corresponding to approximately 1,000 kDa was observed for HuYON007-MVIgG1 in the gel filtration analysis.

**[00233]** The human Burkitt's lymphoma cell line Ramos expresses DR4 on the cell surface (Daniel et al. Blood. 110:4037-4046, 2007). Multimerization of DR4 by cross-linking on the cell surface is known to induce apoptosis of cells (Griffith et al. J. Immunol. 162:2597-2605, 1999). Ramos cells were incubated in RPMI-1640 medium containing 10% FBS in the presence of 200 ng/ml of HuYON007-MVIgG1 or HuYON007-IgG1. The viability of Ramos cells after 24-hr incubation was less than 5% with HuYON007-MVIgG1 whereas the viability was more than 75% with HuYON007-IgG1, indicating that HuYON007-MVIgG1 efficiently induces apoptosis of Ramos cells.

**[00234]** Therapeutic efficacy of HuYON007-MVIgG1 was evaluated using a systemic mouse xenograft model with Ramos cells. CB17 SCID female mice were inoculated on Day 0 with  $5 \times 10^6$  Ramos cells intravenously into the tail vein for tumor development. HuYON007-IgG1 (0.5 mg/kg), HuYON007-MVIgG1 (0.5 mg/kg), or PBS was administered intravenously to the tumor-bearing mice on Days 7, 10, 14, 17, 21, 24, 28, and 31. The mice were monitored daily for morbidity and mortality. Mice were euthanized at the onset of hind leg paralysis or when more than 20% of body weight was lost.

**[00235]** Mice survival was plotted using the Kaplan-Meier method (Fig. 18) and analyzed for significance using the Mantel-Cox test. The mean survival time was 27.5 days for the PBS-treated group, 31.5 days for the group treated with HuYON007-IgG1, and 37.5 days for the group treated with HuYON007-MVIgG1. The P value between the PBS-treated and HuYON007-MVIgG1-treated groups was 0.0019. The P value between the HuYON007-IgG1-treated and HuYON007-MVIgG1-treated groups was 0.0128. HuYON007-MVIgG1

was significantly more efficacious than HuYon007-IgG1 as therapeutics in the mouse systemic xenograft model with Ramos cells.

**[00236]** SEQ ID NO:41 Amino acid sequence of the extracellular region of human DR4 fused to the Fc region of human gamma-1 heavy chain (DR4-Fc)

ASGTEAAAATPSKVWGSSAGRIEPRGGGRGALPTSMQHGAPSARARAGRAPGPRPA  
REASPRLRVHKTFKVVVGVLQVVPSSAATIKLHDQSIGTQQWEHSPLGELCPPGS  
HRSEHPGACNRCTEGVGYTNASNLLFACLPCTACKSDEEERSPCTTRNTACQCKPG  
TFRNDNSAEMCRKCSTGCPGMVKVDCTPWSDIECVHKESGNHGNTGGEPKSC  
DKTHTCPPCPAPELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWY  
VDGVEVHNAKTKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIE  
KTISKAKGQPREPQVYTLPPSRDELTKNQVSLTCLVKGFYPSDIAVEWESNGQPENN  
YKTTPPVLDSDGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPG  
K

**[00237]** SEQ ID NO:46 Nucleotide sequence of an exon encoding HuYON007 VH  
ACTAGTACCACCATGAACAGGGCTTACTCCTCATTGCTGCTGCTGATTGTCCCTGC  
ATATGTCCTGTCCCAGGTACACCTTGAGGGAGTCTGGCCTGCCCTGGTAAACCC  
ACACAGACCCTCACACTGACCTGCACCTCTCTGGTTCTCACTCAGCACTCTG  
GTATGGGTGTGAGCTGGATCAGACAGCCCCCAGGGAAAGGCCCTGGAGTGGCTTG  
CACACATTTACTGGGATGATGACAAGCGCTATAACCCATCCCTGAAGAGCAGGC  
TCACCATCTCCAAGGACACCTCCAAAACCAAGTGGCCTTACAATGACCAACAT  
GGACCCTGTCGACACAGCCACCTATTACTGTACTCGGAGAGGGAGTATGGTAA  
CTTCGACTACTGGGCCAGGGAACCCCTGGTACCGTCTCCTCAGGTGAGTCTGCT  
GTACTGAAGCTT

**[00238]** SEQ ID NO:47 Nucleotide sequence of an exon encoding HuYON007 VL  
GCTAGCACCACCATGGCCTGGATTTCACTTATCCTCTCTCCTGGCTCTCAGCTC  
AGGGGCCATTCCCAGACTGTCGTGACCCAGGAGCCATCCCTCTCAGTGTCCCT  
GGAGGGACAGTCACACTCACTGTCGCTCAAGTTCTGGGGCTGTTACAACCAAGTA  
ACTTGCCAACACTGGTCCAGCAGACCCAGGCCAGGCTCCACGCCCTCATCG  
GCGGTACCAACAACCGAGCTCCAGGGCTGATCGCTCTGGCTCCATCCT  
TGGGAACAAAGCTGCCCTACCACCACTACCGGGGCCAGGCAGATGATGAATCTGA  
TTATTACTGTGCTCTATGGTACAGCAACCACTGGGTGTTGGCGGAGGGACCAAG  
CTGACCGTCCTAGGTGAGTCTCTCCCCGAATTC

**WHAT IS CLAIMED IS:**

1. An antibody or fusion protein comprising an immunoglobulin heavy chain constant region, comprising in order from N- to C-terminus CH2 and CH3 regions, each of which is of IgG or IgA isotype, and C $\mu$ 3 and C $\mu$ 4 regions.
2. The antibody or fusion protein of claim 1, wherein the immunoglobulin heavy chain further comprises a hinge region N-terminal to the CH2 region.
3. The antibody or fusion protein of claim 1, wherein the immunoglobulin heavy chain further comprises a CH1 region N-terminal to the hinge region.
4. The antibody or fusion protein of claim 3, which is an antibody, wherein the heavy chain constant region is fused to a heavy chain variable region and the antibody further comprises a light chain comprising a light chain variable region and constant region.
5. The antibody of claim 4 as a component of a multi-specific antibody comprising a plurality of antibodies as defined in claim 4 with different heavy chain variable regions, and optionally different light chain variable regions; the plurality of antibodies being complexed in the multi-specific antibody via the C $\mu$ 3 and C $\mu$ 4 regions.
6. The antibody or fusion protein of claim 1, wherein the CH1 region, and hinge region, if present, and the CH2 and CH3 regions are IgG1 regions.
7. The antibody or fusion protein of claim 1, wherein the CH1 region and hinge region, if present, and the CH2 and CH3 regions are IgG2 regions.
8. The antibody or fusion protein of claim 1, wherein the CH1 region and the hinge region, if present, and the CH2 and CH3 regions are IgG3 regions.
9. The antibody or fusion protein of claim 1, wherein the CH1 region and the hinge region, if present, and the CH2 and CH3 regions are IgG4 regions.
10. The antibody or fusion protein of claim 1, wherein the CH1 region, if present, and the CH2 and CH3 regions are IgA regions.

11. The antibody or fusion protein of any preceding claim, wherein the CH1 region, and the hinge region, if present, and the CH2 and CH3 regions are human CH1, hinge, CH2 and CH3 regions and the C $\mu$ 3 and C $\mu$ 4 regions are human C $\mu$ 3 and C $\mu$ 4 regions.

12. The antibody or fusion protein of claim 1, which is a single-chain antibody comprising a single-chain Fv linked to the heavy chain constant region.

13. The antibody of claim 12, which is a component of a multi-specific antibody comprising a plurality of single-chain antibodies as defined in claim 12, wherein the scFvs of the plurality have different VH regions, and the plurality of single-chain antibodies are complexed in the multi-specific antibody via the C $\mu$ 3 and C $\mu$ 4 regions.

14. The antibody of claim 13, wherein the scFvs have the same VL region.

15. The antibody or fusion protein of claim 4 in the form of a multimer comprising at least five or six copies of a unit comprising two of the heavy chains and two of the light chains, the copies being complexed in the multimer via the C $\mu$ 3 and C $\mu$ 4 regions.

16. The antibody or fusion protein of claim 2, wherein the CH1 region, if present, the hinge region and CH2 and CH3 regions are IgG and the antibody or fusion protein which shows pH-dependent FcRn binding, specifically binds protein G, specifically binds protein A, exhibits ADCC, CDC and/or opsonization.

17. The antibody or fusion protein of claim 2, wherein the CH1 region, if present, and the hinge region, and CH2 and CH3 regions are human IgG1 regions and the antibody shows pH-dependent FcRn binding, specifically binds protein G, and specifically binds protein A.

18. The antibody of claim 17 that exhibits ADCC, CDC and opsonizaton.

19. The antibody or fusion protein of claim 2, wherein the CH1 region if present, and the hinge, CH2 and CH3 regions are human IgG2 or IgG4 regions and the antibody or fusion protein shows pH-dependent FcRn binding, specifically binds protein G and specifically binds protein A.

20. The antibody or fusion protein of claim 2, wherein the CH1 region if present, and the hinge region, and CH2 and CH3 regions are human IgG3 and the antibody shows pH-dependent FcRn binding, and specifically binds protein G.

21. The antibody or fusion protein of claim 20 that exhibits ADCC, CDC and opsonization.

22. The antibody or fusion protein of claim 1, wherein the CH1, if present, and the CH2 and CH3 regions are human IgA and the antibody binds an Fc alpha receptor.

23. The antibody or fusion protein of claim 1, which is a fusion protein comprising the immunoglobulin heavy chain linked to a heterologous polypeptide.

24. The fusion protein of claim 23, wherein the heterologous protein is linked to the hinge of the constant region via a flexible linker, such as Gly-Gly-Ala-Ala.

25. The fusion protein of claim 23, wherein the heterologous polypeptide is a receptor extracellular domain or a protein that specifically binds to a receptor extracellular domain.

26. The fusion protein of claim 23 as a component of a multi-specific complex comprising a plurality of fusion protein, the fusion proteins including different heterologous polypeptides.

27. The antibody or fusion protein of claim 1 that is a multispecific complex comprising an antibody and a fusion protein complexed via the C $\mu$ 3 and C $\mu$ 4 regions.

28. The antibody or fusion protein of claim 1, wherein the antibody is a humanized, chimeric, veneered or human antibody.

29. The antibody or fusion protein of claim 1 that specifically binds the extracellular domain of a receptor.

30. The antibody or fusion protein of claim 1, which is an antibody that specifically binds to CD79a, CD30, or DR5.

31. The antibody or fusion protein of claim 1, which is a fusion protein comprising an extracellular domain of a TNF-alpha receptor, LFA-3 or an IL-1 receptor.

32. The antibody or fusion protein of claim 1, which is a fusion protein comprising a TRAIL protein.

33. The antibody or fusion protein of claim 1 that is conjugated to a toxic moiety.

34. The antibody or fusion protein of claim 33, wherein the toxic moiety is cytotoxic.

35. A pharmaceutical composition comprising an antibody or fusion protein as defined in claim 1.

36. A method of treating cancer comprising administering to a patient having or at risk of cancer an effective regime of an antibody or fusion protein as defined in claim 1.

37. A method of treating an immunological disorder comprising administering to a patient having or at risk of the disorder an effective regime of an antibody or fusion protein as defined in claim 1.

38. A method of producing a multi-specific complex of antibodies and/or fusion proteins, comprising

a. transfecting a cell with a vector or vectors encoding a plurality of antibodies and/or fusion proteins as defined by claim 1, the antibodies and/or fusion proteins having different specificities; wherein the antibodies and/or fusion proteins are expressed and assembled into a multispecific complex via the C $\mu$ 3 and C $\mu$ 4 regions; and

b. isolating the multi-specific complex from the cell culture.

39. The method of claim 38, wherein each of the plurality of antibodies or fusion proteins is encoded by a different vector.

40. An antibody or fusion protein comprising a hybrid constant region comprising an N-terminal IgG constant region segment and a C-terminal IgM constant region segment; wherein the antibody exhibits pH dependent FcRn binding, specifically binds protein G, and multimerizes to form at least a pentamer or hexamer via the IgM constant region.

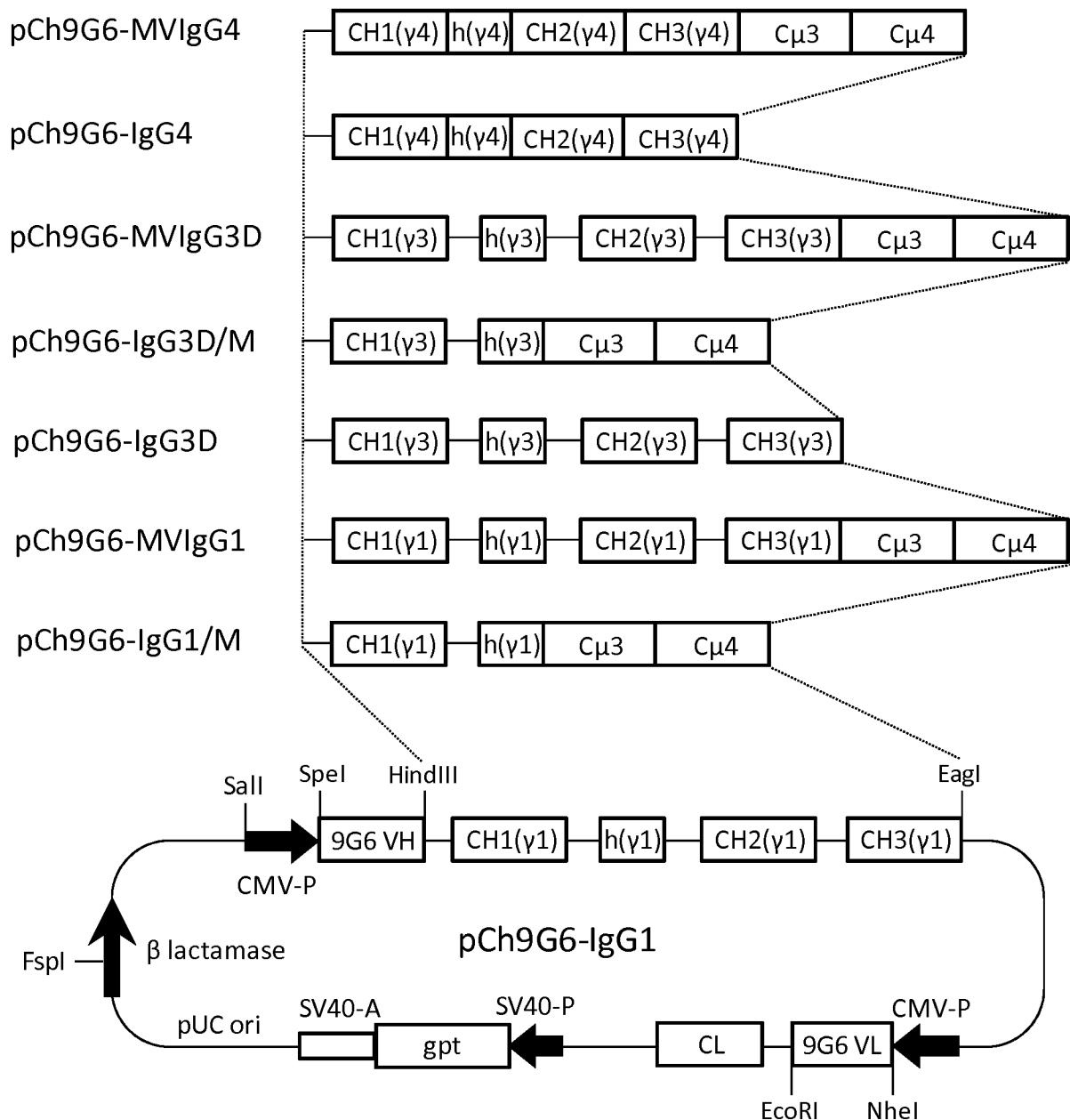


Figure 1

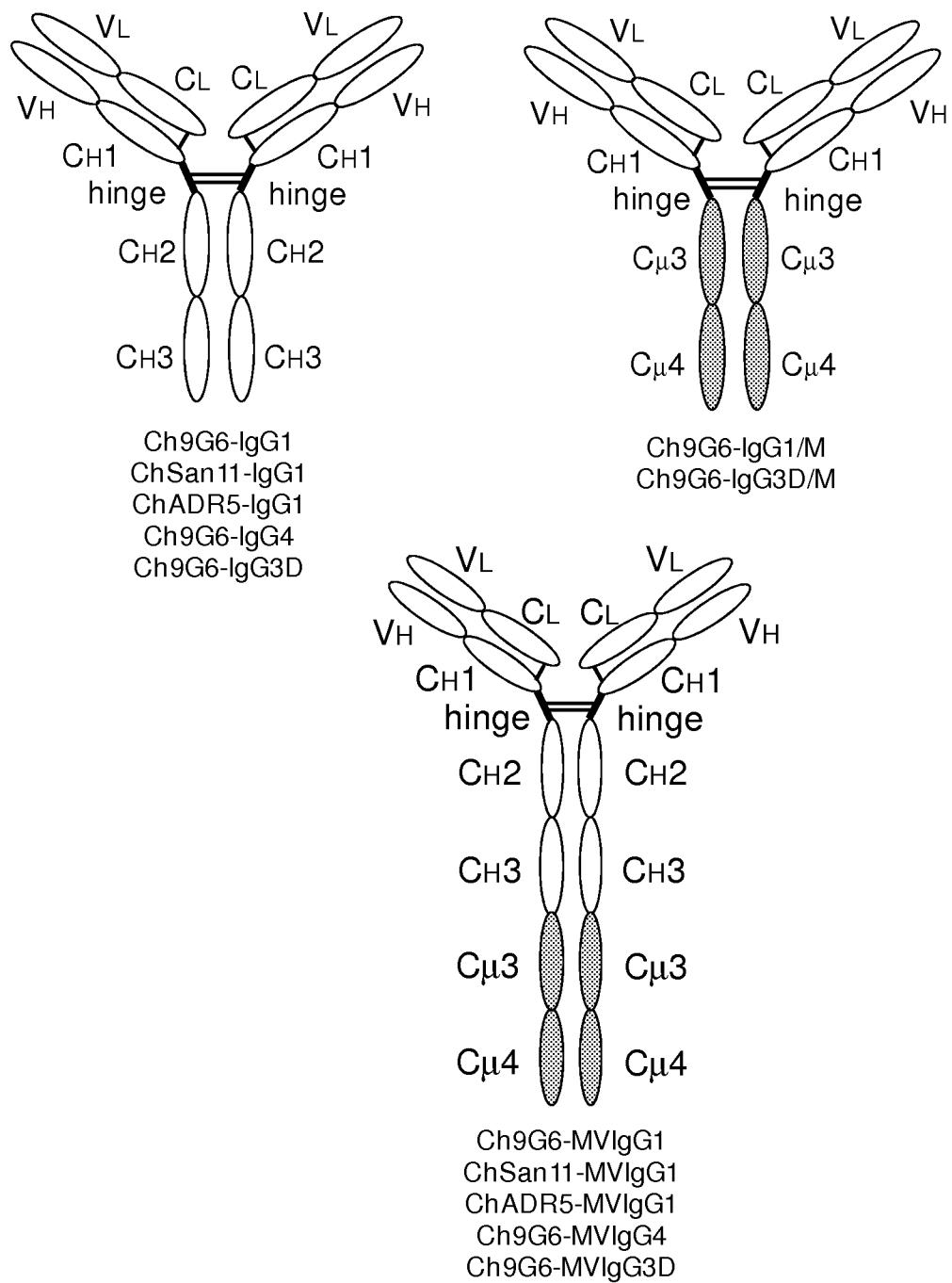
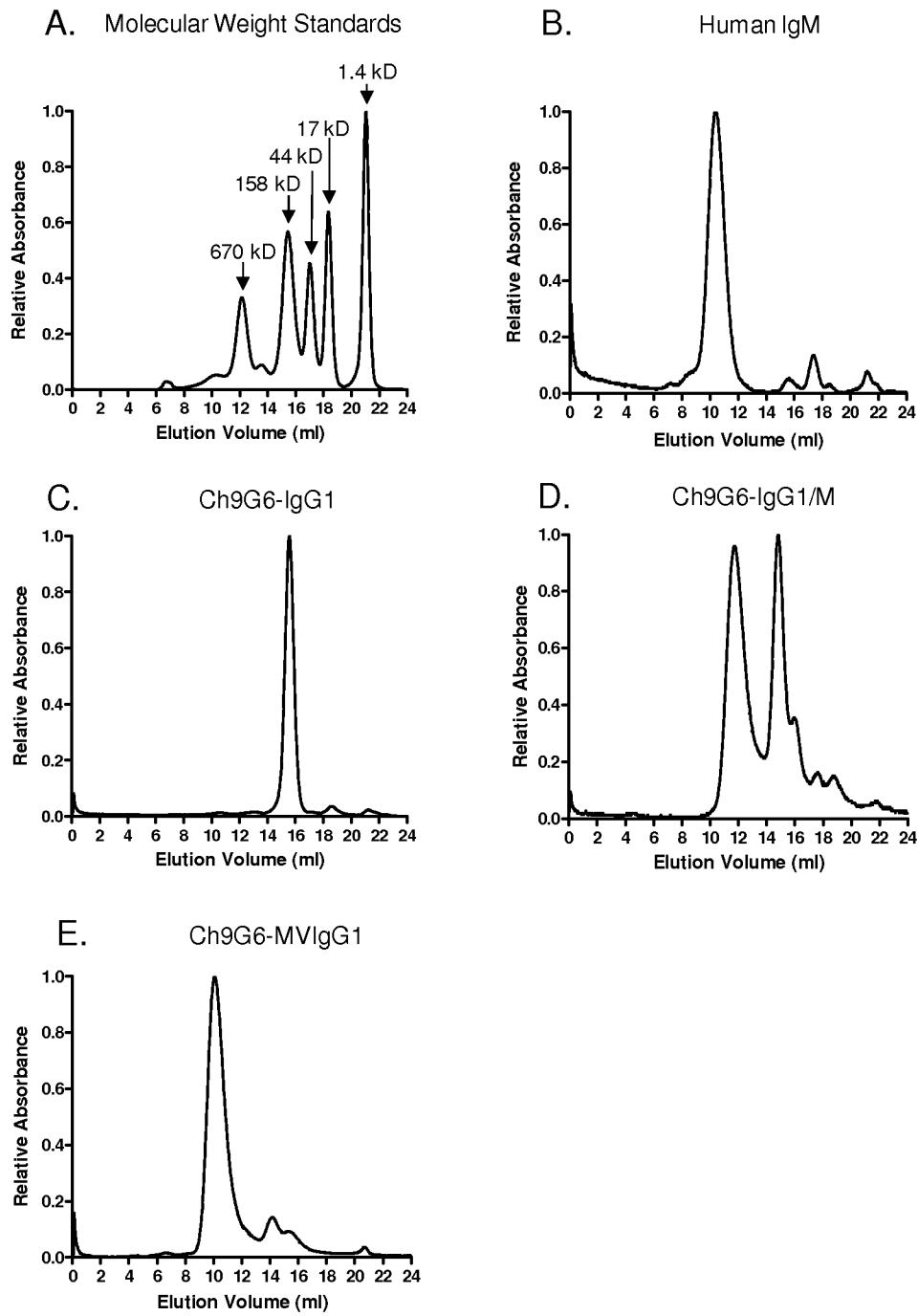


Figure 2

## Elution Pattern of Superose 6 Gel Filtration



Figures 3A-E

### Induction of Apoptosis of Ramos Cells by Multivalent IgG

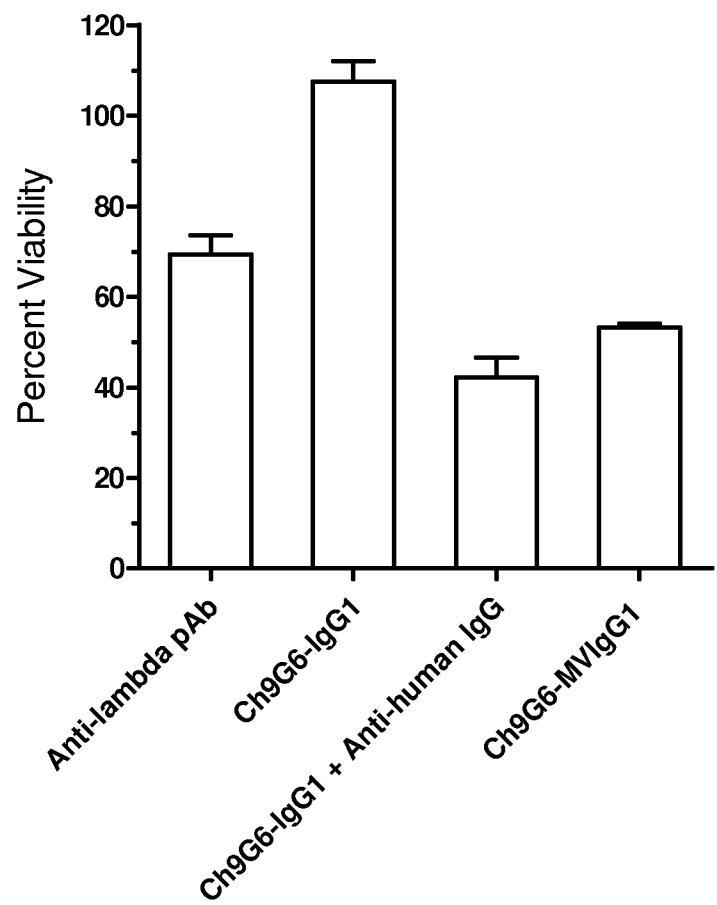


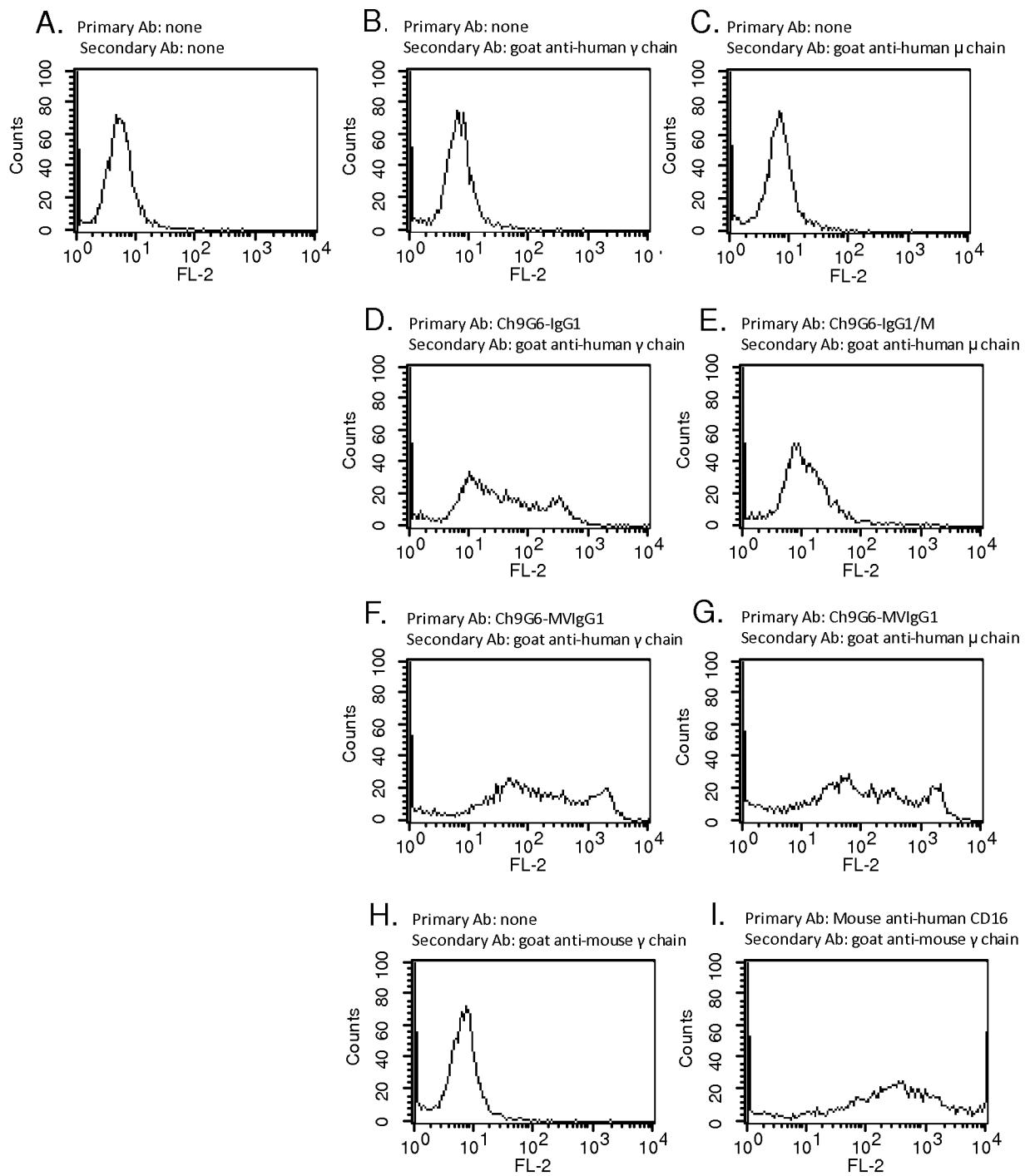
Figure 4

## pH-Dependent Binding of Multivalent IgG1 to FcRn

| Primary Antibody | PE-labeled Secondary Antibody | Mean Channel Fluorescence |        |
|------------------|-------------------------------|---------------------------|--------|
|                  |                               | pH 6.0                    | pH 7.5 |
| None             | Goat anti-human gamma chain   | 4.2                       | 3.3    |
| None             | Goat anti-human mu chain      | 8.7                       | 4.1    |
| Ch9G6-IgG1       | Goat anti-human gamma chain   | 324.9                     | 11.3   |
| Ch9G6-IgG1/M     | Goat anti-human mu chain      | 19.4                      | 3.4    |
| Ch9G6-MVIgG1     | Goat anti-human mu chain      | 765.8                     | 107.0  |

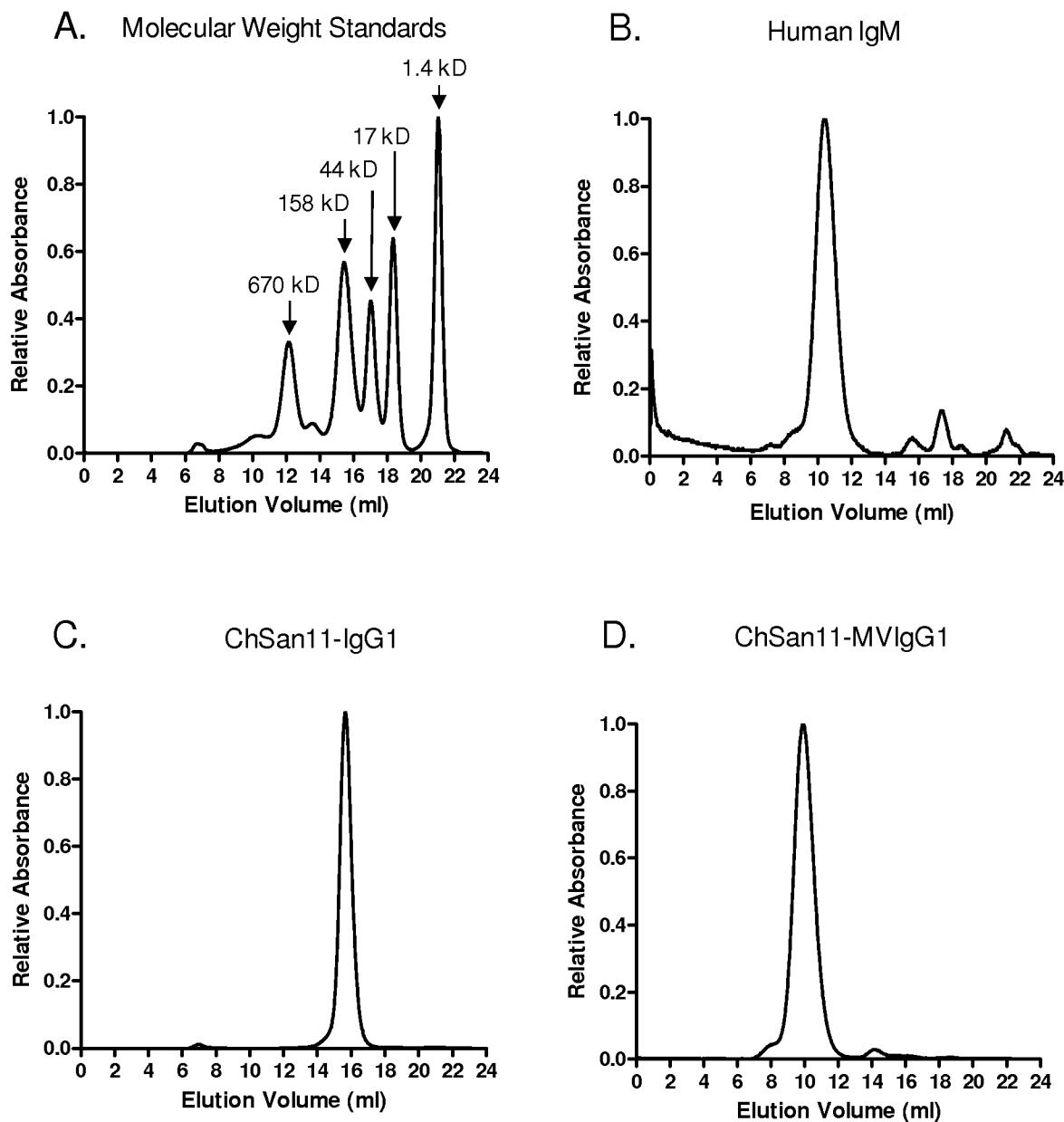
Figure 5

## Binding of multivalent IgG1 antibodies to CD16



Figures 6A-I

## Elution Pattern of Superose 6 Gel Filtration



Figures 7A-D

### Growth Arrest of Karpas 299 Cells by Multivalent IgG

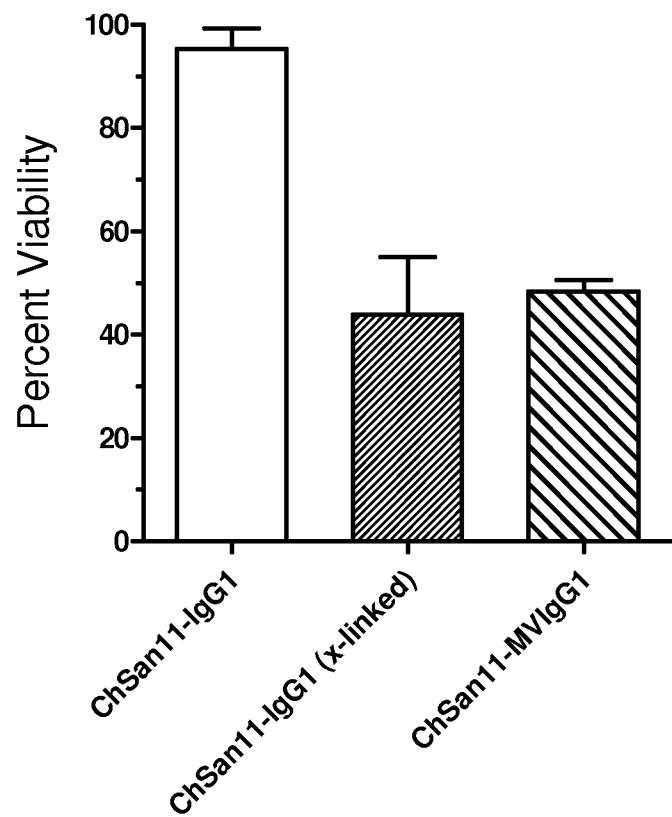


Figure 8

## Presence of ChSan11-MVIgG1 in Superose 6 fractions

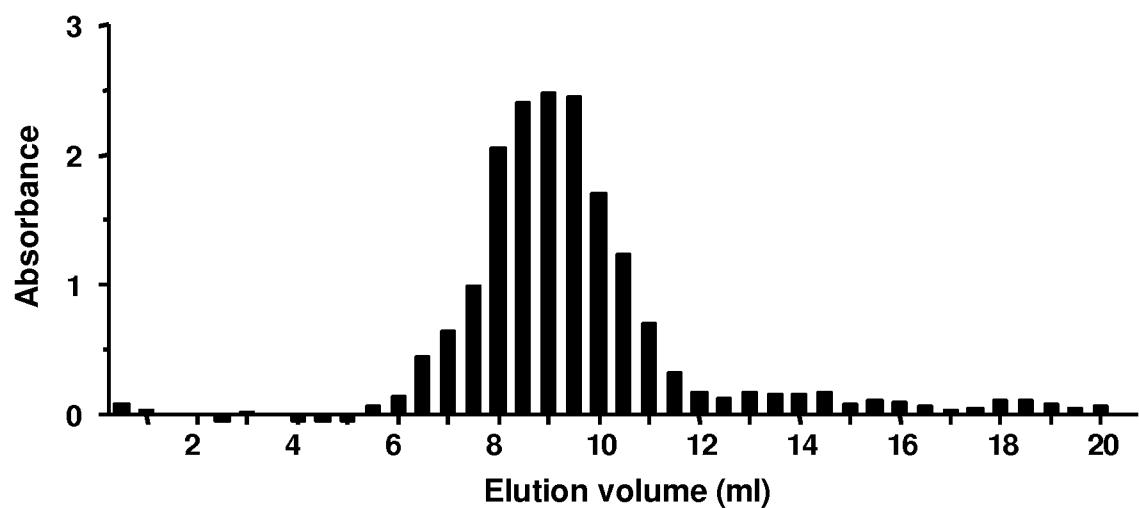
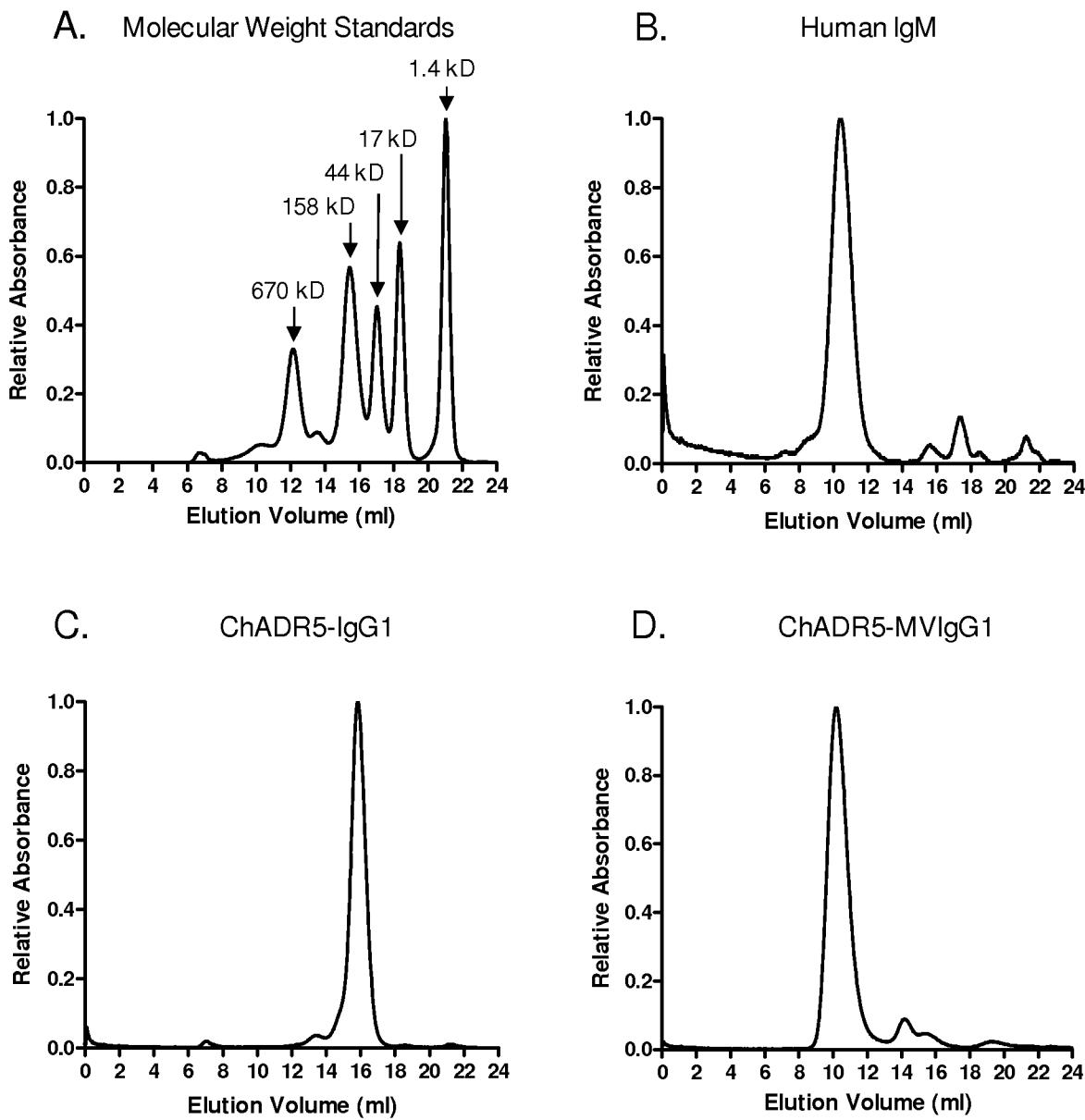


Figure 9

## Elution Pattern of Superose 6 Gel Filtration



Figures 10A-D

### Apoptosis of Jurkat Cells Induced by Multivalent IgG

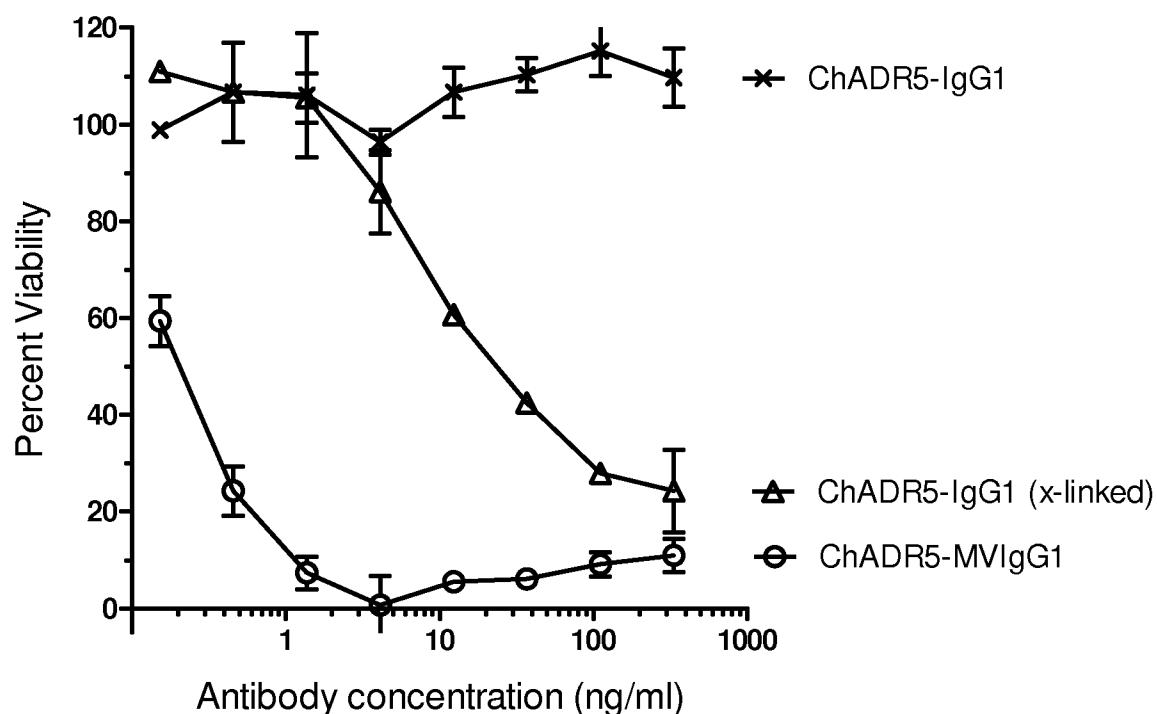
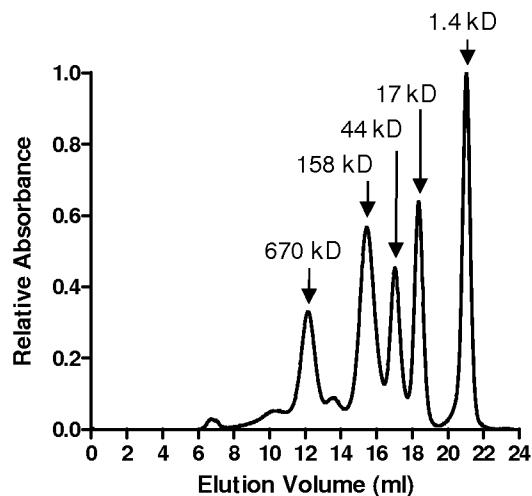


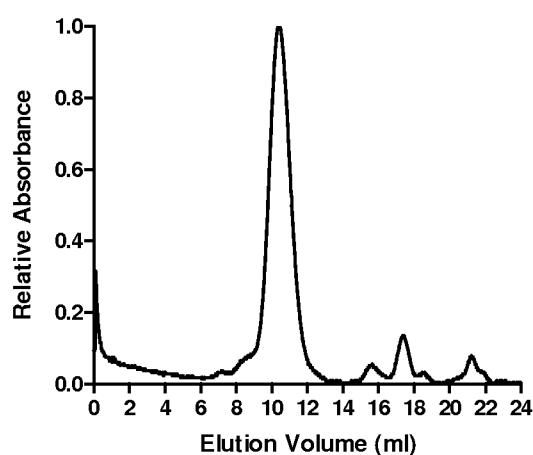
Figure 11

## Elution Pattern of Superose 6 Gel Filtration

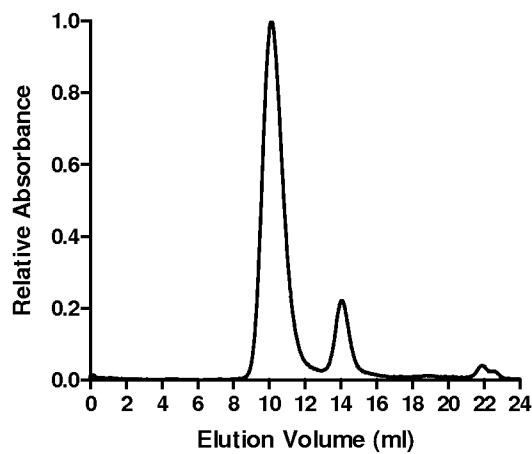
A. Molecular Weight Standards



B. Human IgM

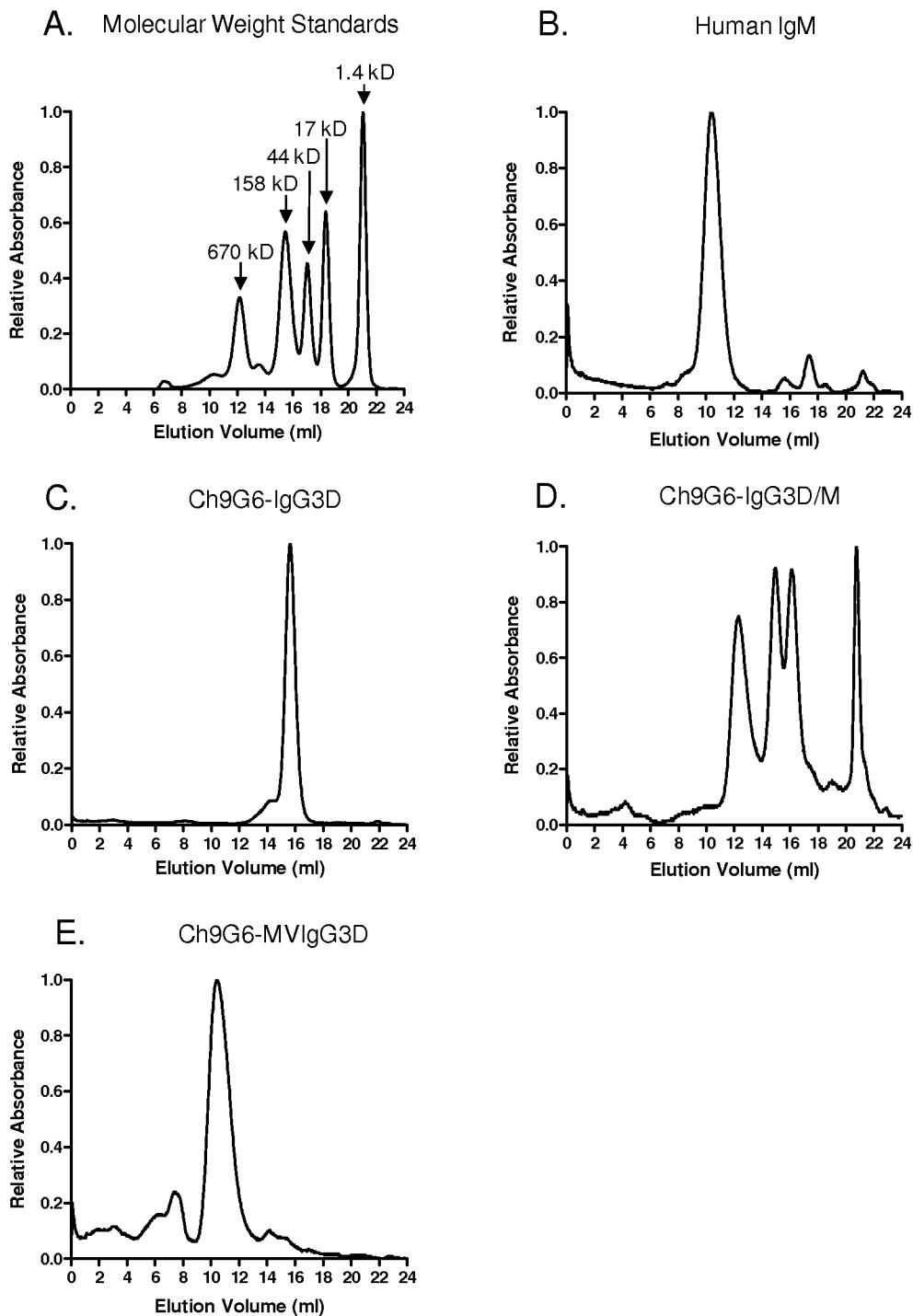


C. Ch9G6-MVIgG4



Figures 12A-C

## Elution Pattern of Superose 6 Gel Filtration



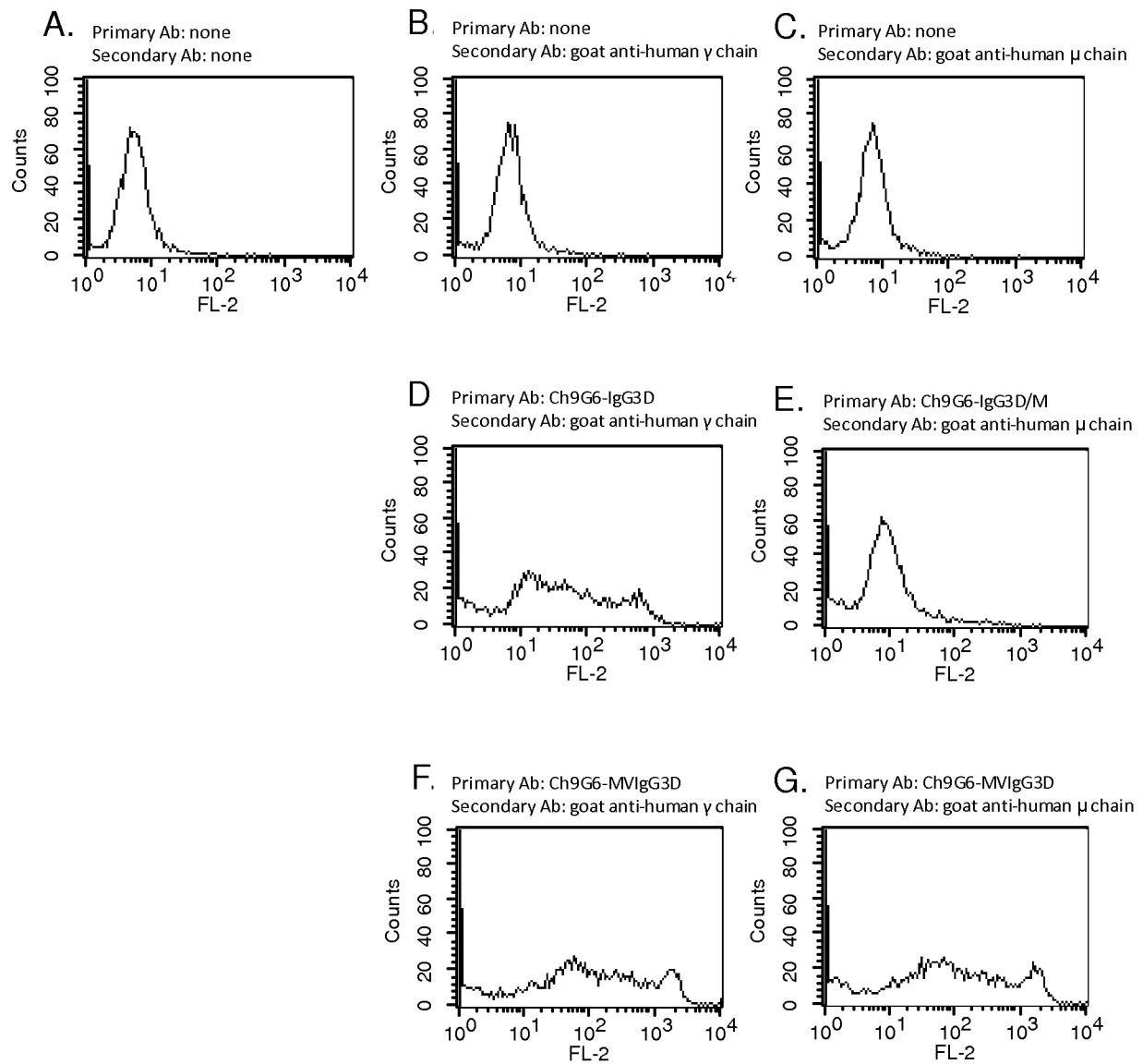
Figures 13A-E

## pH-Dependent Binding of Multivalent IgG3 to FcRn

| Primary Antibody | PE-labeled Secondary Antibody | Mean Channel Fluorescence |        |
|------------------|-------------------------------|---------------------------|--------|
|                  |                               | pH 6.0                    | pH 7.5 |
| None             | Goat anti-human gamma chain   | 4.2                       | 3.3    |
| None             | Goat anti-human mu chain      | 8.7                       | 4.1    |
| Ch9G6-IgG3D      | Goat anti-human gamma chain   | 447.4                     | 20.6   |
| Ch9G6-IgG3D/M    | Goat anti-human mu chain      | 11.4                      | 3.2    |
| Ch9G6-MVIgG3D    | Goat anti-human mu chain      | 962.1                     | 146.5  |

Figure 14

## Binding of multivalent IgG3 antibodies to CD16



Figures 15A-G

**Figure 16A****Human gamma-1 heavy chain constant region**

CH1: ASTKGPSVPLAPSSKSTSGGTAALGCLVKDYFPEPVTVWNNSGALTSGVHTFPALQSS  
GLYSLSSVTVPSSSLGTQTYICNVNHKPSNTKVDKKV (SEQ ID NO:15)

Hinge: EPKSCDKTHCPPCP (SEQ ID NO:16)

CH2: APELLGGPSVFLFPPPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAKTK  
PREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAK (SEQ ID  
NO:17)

CH3: GQPREPQVYTLPPSRDELTQNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTPPVLD  
DGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK (SEQ ID NO:18)

**Human gamma-2 heavy chain constant region**

CH1: ASTKGPSVPLAPCSRSTSESTAALGCLVKDYFPEPVTVWNNSGALTSGVHTFPALQSS  
GLYSLSSVTVPSSNFGTQTYTCNVDHKPSNTKVDKTV (SEQ ID NO:19)

Hinge: ERKCCVECPPCP (SEQ ID NO:20)

CH2: APPVAGPSVFLFPPPKDTLMISRTPEVTCVVVDVSHEDPEVQFNWYVDGVEVHNAKTKP  
REEQFNSTFRVVSVLTVVHQDWLNGKEYKCKVSNKGLPAPIEKTISKTK (SEQ ID NO:21)

CH3: GQPREPQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTPPMLDS  
DGSFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK (SEQ ID NO:22)

**Human gamma-3 heavy chain constant region**

CH1: ASTKGPSVPLAPCSRSTSGGTAALGCLVKDYFPEPVTVWNNSGALTSGVHTFPALQSS  
GLYSLSSVTVPSSSLGTQTYTCNVNHKPSNTKVDKRV (SEQ ID NO:23)

Hinge: ELKTPLGDTTHTCPRCPEPKSCDTPPPCPRCPEPKSCDTPPPCPRCPEPKSCDTPPPC  
PRCP (SEQ ID NO:24)

CH2: APELLGGPSVFLFPPPKDTLMISRTPEVTCVVVDVSHEDPEVQFKWYVDGVEVHNAKTK  
PREEQYNSTFRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKTK (SEQ ID  
NO:25)

CH3: GQPREPQVYTLPPSREEMTKNQVSLTCLVKGFYPSDIAVEWESSGQPENNYNTPPMLDS  
DGSFFLYSKLTVDKSRWQQGNIFSCSVMHEALHNRTQKSLSLSPGK (SEQ ID NO:26)

**Figure 16B****Human gamma-4 heavy chain constant region**

CH1: ASTKGPSVPLAPCSRSTSESTAALGCLVKDYFPEPVTVWNMGALTSGVHTFPALQSS  
GLYSLSSVVTVPSSSLGTKYTCNVDHKPSNTKVDKRV (SEQ ID NO:27)

Hinge: ESKYGPPCPSCP (SEQ ID NO:28)

CH2: APEFLGGPSVFLFPPPKDTLMISRTPEVTCVVVDVSQEDPEVQFNWYVDGVEVHNAKTK  
PREEQFNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKGLPSSIEKTISKAK (SEQ ID  
NO:29)

CH3: GQPREPQVYTLPPSQEEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTPPVLD  
DGSSFLYSLTVDKSRWQEGNVFSCSVMHEALHNHYTQKSLSLSLGK (SEQ ID NO:30)

**Human alpha-1 heavy chain constant region**

CH1: ASPTSPKVPLSLCSTQPDGNVVIACLVQGFPQEPLSVTWSESGQGVTARNFPPSQDAS  
GDLYTTSSQLTPATQCLAGKSVTCHVHYTNPSQDVTVPSCP (SEQ ID NO:31)

CH2: VPSTPPTPSPSTPPTSPSCCHPRSLHRPALEDLLLGEANLTCTLTGLRDASGVFTFW  
TPSSGKSAVQGPPERDLCGCVSVSSVLPGCAEPWNHGKTFCTAAYPESKTPLATLSKS  
(SEQ ID NO:32)

CH3: GNTFRPEVHLLPPPSEELALNELVLTCLARGFSPKDVLVRWLQGSQELPREKYL  
TWASRQEPSQGTTFAVTSILRVAEDWKKGDTFSCMVGHEALPLAFTQKTI  
DRLAGKPTHNVSVVMAEVDGTCY (SEQ ID NO:33)

**Human alpha-2 heavy chain constant region**

CH1: ASPTSPKVPLSLDSTPQDGNNVVACLVQGFPQEPLSVTWSESGQNV  
TARNFPPSQDASGDLYTTSSQLTPATQCPDGKSVTCHVHYTNPSQDVTVPSCP (SEQ ID NO:34)

CH2: VPPPPCCCHPRSLHRPALEDLLLGEANLTCTLTGLRDASGATFTWTPSSGKSAVQGP  
PERDLCGCVSVSSVLPGCAQWPWNHGETFTCTAAHPELKTPLTANITKS (SEQ ID NO:35)

CH3: GNTFRPEVHLLPPPSEELALNELVLTCLARGFSPKDVLVRWLQGSQELPREKYL  
TWASRQEPSQGTTFAVTSILRVAEDWKKGDTFSCMVGHEALPLAFTQKTI  
DRLAGKPTHNVSVVMAEVDGTCY (SEQ ID NO:36)

**Figure 16C****Human mu heavy chain constant region**

C $\mu$ 1: GSASAPTLFPLVSCENS P S D T S S V A V G C L A Q D F L P D S I T F S W K Y K N N S D I S S T R G F P S V L R G G K Y A A T S Q V L L P S K D V M Q G T D E H V V C K V Q H P G N K E K N V P L P (SEQ ID NO:51)

C $\mu$ 2: V I A E L P P K V S V F V P P R D G F F G N P R K S K L I C Q A T G F S P R Q I Q V S W L R E G K Q V G S G V T T D Q V Q A E A K E S G P T T Y K V T S T L T I K E S D W L S Q S M F T C R V D H R G L T F Q Q N A S S M C V P (SEQ ID NO:52)

C $\mu$ 3: D Q D T A I R V F A I P P S F A S I F L T K S T K L T C L V T D L T T Y D S V T I S W T R Q N G E A V K T H T N I S E S H P N A T F S A V G E A S I C E D D W N S G E R F T C T V T H D L P S P L K Q T I S R P K (SEQ ID NO:53)

C $\mu$ 4: G V A L H R P D V Y L L P P A R E Q L N L R E S A T I T C L V T G F S P A D V F V Q W M Q R G Q P L S P E K Y V T S A P M P E P Q A P G R Y F A H S I L T V S E E E W N T G E T Y T C V V A H E A L P N R V T E R T V D K S T G K P T L Y N V S L V M S D T A G T C Y (SEQ ID NO:54)

**J-Chain (aa1-22=signal peptide)**

M K N H L L F W G V L A V F I K A V H V K A Q E D E R I V L V D N K C K C A R I T S R I I R S S E D P N E D I V E R N I R I I V P L N N R E N I S D P T S P L R T R F V Y H L S D L C K C D P T E V E L D N Q I V T A T Q S N I C D E D S A T E T C Y T Y D R M K C Y T A V V P L V Y G G E T K M V E T A L T P D A C Y P D (SEQ ID NO:55)

Figure 17

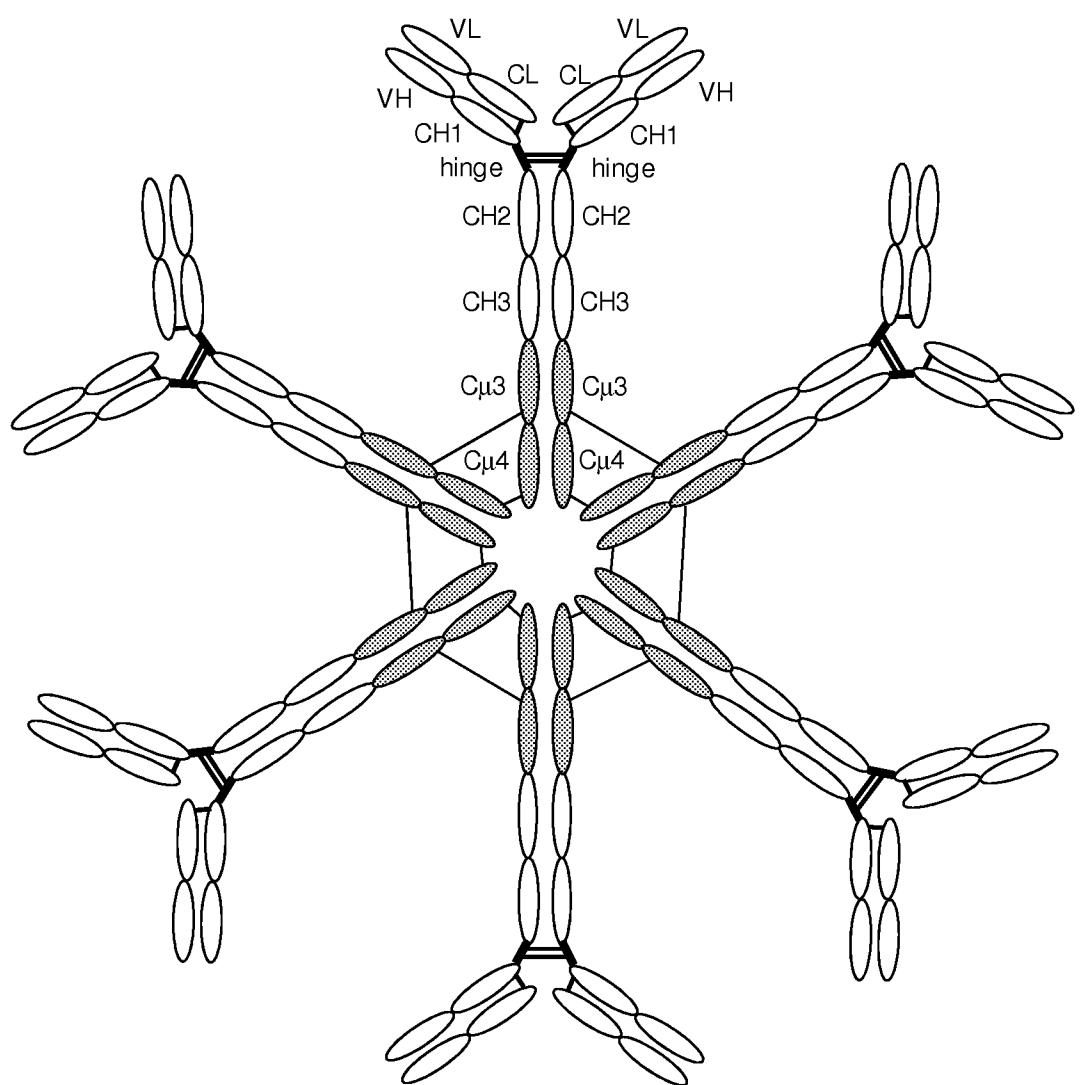
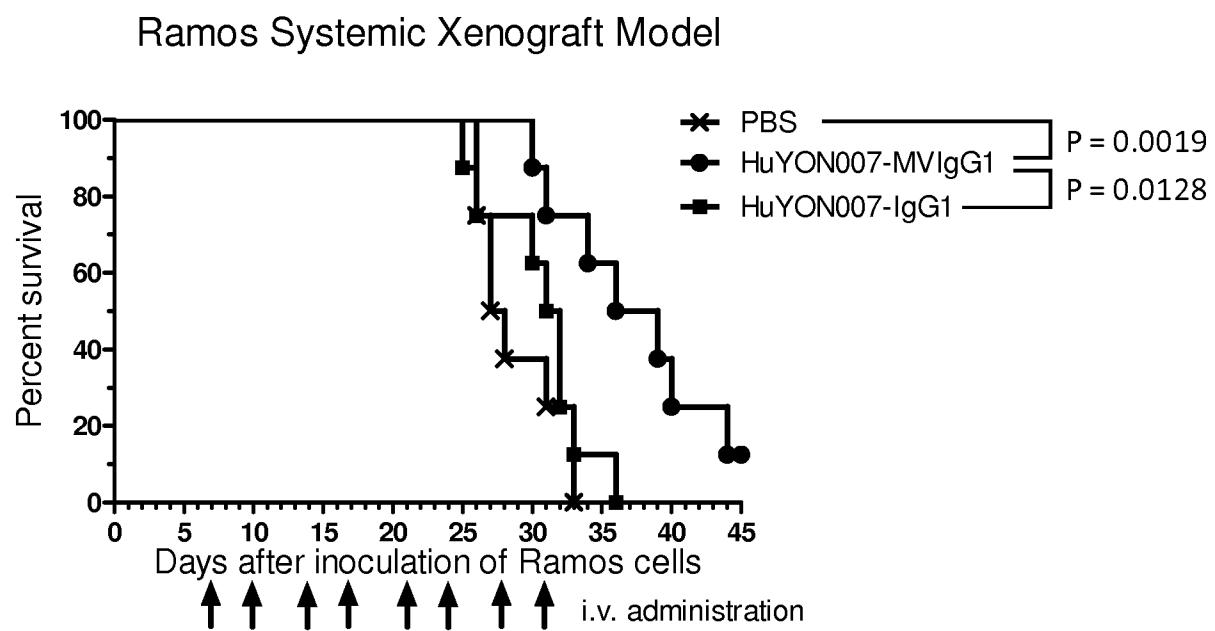


Figure 18



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US2012/057393

## A. CLASSIFICATION OF SUBJECT MATTER

*C07K 16/28(2006.01)i, C07K 19/00(2006.01)i, C12N 15/13(2006.01)i, C12N 15/62(2006.01)i, A61K 39/395(2006.01)i, A61P 35/00(2006.01)i*

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C07K 16/28; C12N 5/06; A61K 39/385; C07K 14/00; A61P 35/00; C12P 21/02; C07K 16/30

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
Korean utility models and applications for utility models  
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
eKOMPASS(KIPO internal) & Keywords: recombinant antibody, hybrid constant CH2, CH3, C  $\mu$  3, C  $\mu$  4 regions

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | US7951378 B2 (LARRICK, JAMES WILLIAM et al.) 31 May 2011<br>See abstract; column 15, paragraph 1.                                                                                                                                                                 | 1-35,38-40            |
| A         | WO2008148884 A1 (UNIVERSITE DE LA MEDITERRANEE et al.) 11 December 2008<br>See abstract; claims 19-23.                                                                                                                                                            | 1-35,38-40            |
| A         | US20040175786 A1 (CHOI, INGRID et al.) 09 September 2004<br>See claim 1; fig. 2.                                                                                                                                                                                  | 1-35,38-40            |
| A         | BARFOD, L. et al., 'Evasion of immunity to Plasmodium falciparum malaria by IgM masking of protective IgG epitopes in infected erythrocyte surface-exposed PfEMP1', PNAS, 26 July 2011, Vol.108, No.30, pp.12485-12490.<br>See p.12487, left column, paragraph 1. | 1-35,38-40            |
| A         | GHUMRA, A. et al., 'Structural requirements for the interaction of human IgM and IgA with the human Fc $\alpha$ / $\mu$ receptor', European Journal of Immunology, April 2009, Vol.39, No.4, pp.1-19.<br>See abstract.                                            | 1-35,38-40            |

Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents:  
"A" document defining the general state of the art which is not considered to be of particular relevance  
"E" earlier application or patent but published on or after the international filing date  
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)  
"O" document referring to an oral disclosure, use, exhibition or other means  
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone  
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art  
"&" document member of the same patent family

Date of the actual completion of the international search  
27 FEBRUARY 2013 (27.02.2013)

Date of mailing of the international search report

**28 FEBRUARY 2013 (28.02.2013)**

Name and mailing address of the ISA/KR



Facsimile No. 82-42-472-7140

Authorized officer

HEO, Joo Hyung

Telephone No. 82-42-481-8150



**INTERNATIONAL SEARCH REPORT**

International application No.

**PCT/US2012/057393****Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.: 36,37  
because they relate to subject matter not required to be searched by this Authority, namely:  
Claims 36 and 37 pertain to methods for treatment of the human body by therapy, and thus relate to a subject matter which this International Searching Authority is not required, under Article 17(2)(a)(i) of the PCT and Rule 39.1(iv) of the Regulations under the PCT, to search.
2.  Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3.  Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2012/057393**

| Patent document cited in search report | Publication date | Patent family member(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Publication date                                                                                                                                                                                                                                                                                                                                                                       |
|----------------------------------------|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| US7951378 B2                           | 31.05.2011       | AT 442386 T<br>AU 2001-257445 B2<br>AU 2001-57445 A1<br>AU 2002-365222 A1<br>CA 2407426 A1<br>CA 2464869 A1<br>CN 101643512 A<br>CN 1440423 A0<br>CN 1717417 A<br>DE 60139864 D1<br>DK 1290027 T3<br>EP 1290027 A2<br>EP 1290027 B1<br>EP 1453862 A2<br>EP 1453862 A4<br>EP 2292658 A2<br>EP 2292658 A3<br>ES 2332872 T3<br>JP 2003-531633 A<br>JP 2005-522998 A<br>JP 2010-241817 A<br>JP 5008811 B2<br>US 2002-0168367 A1<br>US 2006-0015969 A1<br>US 2008-0219999 A1<br>WO 01-83529 A2<br>WO 03-064992 A2 | 15.09.2009<br>02.11.2006<br>12.11.2001<br>02.09.2003<br>08.11.2001<br>07.08.2003<br>10.02.2010<br>03.09.2003<br>04.01.2006<br>22.10.2009<br>18.01.2010<br>12.03.2003<br>09.09.2009<br>08.09.2004<br>17.10.2007<br>09.03.2011<br>21.03.2012<br>15.02.2010<br>28.10.2003<br>04.08.2005<br>28.10.2010<br>08.06.2012<br>14.11.2002<br>19.01.2006<br>11.09.2008<br>08.11.2001<br>07.08.2003 |
| WO2008148884 A1                        | 11.12.2008       | AU 2008-258503 A1<br>CA 2689938 A1<br>CN 101778867 A<br>EP 2162471 A1<br>JP 2010-532976 A<br>US 2010-0124555 A1                                                                                                                                                                                                                                                                                                                                                                                              | 11.12.2008<br>11.12.2008<br>14.07.2010<br>17.03.2010<br>21.10.2010<br>20.05.2010                                                                                                                                                                                                                                                                                                       |
| US20040175786 A1                       | 09.09.2004       | DE 10001372 A1<br>EP 1250443 A2<br>WO 01-51644 A2                                                                                                                                                                                                                                                                                                                                                                                                                                                            | 02.08.2001<br>23.10.2002<br>19.07.2001                                                                                                                                                                                                                                                                                                                                                 |