

ANTI-C5 ANTIBODIES AND USES THEREOF

[001] This application is being filed on June 13, 2017 as a PCT International Patent Application and claims the benefit of priority to US provisional application Nos. 62/349,705, filed on June 14, 2016; 62/405,561, filed on October 7, 2016; and 62/422,107, filed on November 15, 2016, the disclosures of each herein incorporated by reference in their entirety.

FIELD OF THE INVENTION

[002] The present invention is related to antibodies and antigen-binding fragments of antibodies that specifically bind to complement factor C5, and therapeutic and diagnostic methods of using those antibodies.

BACKGROUND OF THE INVENTION

[003] The complement system is a group of plasma proteins that when activated lead to target cell lysis and facilitate phagocytosis through opsonization. Complement is activated through a series of proteolytic steps by three major pathways: the classical pathway, which is typically activated by immune-complexes, the alternative pathway that can be induced by unprotected cell surfaces, and the mannose binding lectin pathway. All three pathways of complement cascade converge on proteolytic cleavage of complement component 5 (C5) protein. Cleavage of complement component 5 (C5) results in the production of fragments C5a and C5b, a process that is critical during the activation of the complement cascade. C5a can generate pleiotropic physiological responses through binding to its receptors (Monk *et al* 2007, Br. J. Pharmacol. 152: 429-448). C5a is a potent pro-inflammatory mediator that induces chemotactic migration, enhances cell adhesion, stimulates the oxidative burst, and induces the release of various inflammatory mediators such as histamine or cytokines. C5b mediates the formation of the membrane-attack complex (MAC, or C5b-9) leading to cell lysis in the late phases of the complement dependent cytotoxicity (CDC). Further, in nucleated cells that are resistant to cytolysis by C5b-9, sublytic quantities of C5b-9 can cause cellular activation which results in cell proliferation, generation of pro-inflammatory mediators and production of extracellular matrix.

[004] Monoclonal antibodies to C5 are known in the art and have been described, for example, in US Patent/Publication Nos. 9206251, 9107861, 9079949, 9051365,

8999340, 8883158, 8241628, 7999081, 7432356, 7361339, 7279158, 6534058, 6355245, 6074642, 20160299305, 20160051673, 20160031975, 20150158936, 20140056888, 20130022615, 20120308559, and in WO2015198243, WO2015134894, WO2015120130, EP2563813B1, EP2328616B1, and EP2061810B1.

[005] Fully human antibodies that specifically bind to C5 protein with high affinity and have improved pharmacokinetic properties could be important in the prevention and treatment of various C5-associated diseases (*e.g.*, atypical hemolytic uremic syndrome).

BRIEF SUMMARY OF THE INVENTION

[006] The present invention provides antibodies and antigen-binding fragments thereof that specifically bind complement factor 5 (C5) protein. The antibodies of the present invention are useful, *inter alia*, for inhibiting or neutralizing the activity of C5 protein. In certain embodiments, the antibodies are useful in preventing, treating or ameliorating at least one symptom or indication of a C5-associated disease or disorder in a subject. In certain embodiments, the antibodies may be administered prophylactically or therapeutically to a subject having or at risk of having a C5-associated disease or disorder. In certain embodiments, the anti-C5 antibodies are fully human antibodies that bind to C5 with high affinity and have improved pharmacokinetic (PK) and pharmacodynamic (PD) properties. Such high-affinity antibodies with improved PK/PD can be used to provide superior efficacy, along with less frequent dosing in a subject with a C5-associated disease or disorder.

[007] The antibodies of the invention can be full-length (for example, an IgG1 or IgG4 antibody) or may comprise only an antigen-binding portion (for example, a Fab, F(ab')₂ or scFv fragment), and may be modified to affect functionality, *e.g.*, to increase persistence in the host or to eliminate residual effector functions (Reddy *et al.*, 2000, J. Immunol. 164:1925-1933). In certain embodiments, the antibodies may be bispecific.

[008] In a first aspect, the present invention provides isolated recombinant monoclonal antibodies or antigen-binding fragments thereof that bind specifically to the C5 protein. In some embodiments, the antibodies are fully human monoclonal antibodies.

[009] Exemplary anti-C5 antibodies of the present invention are listed in Tables 1 and 2 herein. Table 1 sets forth the amino acid sequence identifiers of the heavy chain variable regions (HCVRs), light chain variable regions (LCVRs), heavy chain complementarity determining regions (HCDR1, HCDR2 and HCDR3), and light chain complementarity determining regions (LCDR1, LCDR2 and LCDR3) of exemplary

anti-C5 antibodies. Table 2 sets forth the nucleic acid sequence identifiers of the HCVRs, LCVRs, HCDR1, HCDR2 HCDR3, LCDR1, LCDR2 and LCDR3 of the exemplary anti-C5 antibodies.

[010] The present invention provides antibodies, or antigen-binding fragments thereof, comprising an HCVR comprising an amino acid sequence selected from any of the HCVR amino acid sequences listed in Table 1, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[011] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising an LCVR comprising an amino acid sequence selected from any of the LCVR amino acid sequences listed in Table 1, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[012] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising an HCVR and an LCVR amino acid sequence pair (HCVR/LCVR) comprising any of the HCVR amino acid sequences listed in Table 1 paired with any of the LCVR amino acid sequences listed in Table 1. According to certain embodiments, the present invention provides antibodies, or antigen-binding fragments thereof, comprising an HCVR/LCVR amino acid sequence pair contained within any of the exemplary anti-C5 antibodies listed in Table 1. In certain embodiments, the HCVR/LCVR amino acid sequence pair is selected from the group consisting of SEQ ID NOs: 2/10, 18/26, 34/42, 50/58, 66/74, 82/90, 98/106, 98/114, 122/106, 98/130, 138/106, 146/106, 122/130, 146/114, 146/130, 138/130, 154/162, 170/178, 186/194, 202/210, 218/226, 234/242, 250/258, 266/258, 274/282, 290/298, 306/314, 322/330, and 338/346. In certain embodiments, the HCVR/LCVR amino acid sequence pair is selected from one of SEQ ID NOs: 50/58 (*e.g.*, H4H12161P), 98/106 (*e.g.*, H4H12166P), 138/106 (*e.g.*, H4H12166P5), or 202/210 (*e.g.*, H4H12170P). In certain embodiments, the present invention provides anti-C5 antibodies or antigen-binding fragments thereof comprising a HCVR and a LCVR, said HCVR comprising an amino acid sequence listed in Table 1 having no more than five amino acid substitutions, and said LCVR comprising an amino acid sequence listed in Table 1 having no more than two amino acid substitutions. For example, the present invention provides anti-C5 antibodies or antigen-binding fragments thereof comprising a HCVR and a LCVR, said HCVR comprising an amino acid sequence of SEQ ID NO: 98 having no more than

five amino acid substitutions, and said LCVR comprising an amino acid sequence of SEQ ID NO: 106 having no more than two amino acid substitutions. In another embodiment, the present invention provides anti-C5 antibodies or antigen-binding fragments thereof comprising a HCVR and a LCVR, said HCVR comprising an amino acid sequence of SEQ ID NO: 98 having at least one amino acid substitution, and said LCVR comprising an amino acid sequence of SEQ ID NO: 106 having one amino acid substitution.

[013] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a heavy chain CDR1 (HCDR1) comprising an amino acid sequence selected from any of the HCDR1 amino acid sequences listed in Table 1 or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[014] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a heavy chain CDR2 (HCDR2) comprising an amino acid sequence selected from any of the HCDR2 amino acid sequences listed in Table 1 or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[015] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a heavy chain CDR3 (HCDR3) comprising an amino acid sequence selected from any of the HCDR3 amino acid sequences listed in Table 1 or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[016] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a light chain CDR1 (LCDR1) comprising an amino acid sequence selected from any of the LCDR1 amino acid sequences listed in Table 1 or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[017] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a light chain CDR2 (LCDR2) comprising an amino acid sequence selected from any of the LCDR2 amino acid sequences listed in Table 1 or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[018] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a light chain CDR3 (LCDR3) comprising an amino acid sequence

selected from any of the LCDR3 amino acid sequences listed in Table 1 or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity.

[019] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising an HCDR3 and an LCDR3 amino acid sequence pair (HCDR3/LCDR3) comprising any of the HCDR3 amino acid sequences listed in Table 1 paired with any of the LCDR3 amino acid sequences listed in Table 1. According to certain embodiments, the present invention provides antibodies, or antigen-binding fragments thereof, comprising an HCDR3/LCDR3 amino acid sequence pair contained within any of the exemplary anti-C5 antibodies listed in Table 1. In certain embodiments, the HCDR3/LCDR3 amino acid sequence pair is selected from the group consisting of SEQ ID NOs: 56/64 (*e.g.*, H4H12161P), 104/112 (*e.g.*, H4H12166P), 144/112 (*e.g.*, H4H12166P5), and 208/216 (*e.g.*, H4H12170P).

[020] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a HCVR and a LCVR, said HCVR comprising HCDR1 comprising an amino acid sequence differing from an amino acid sequence listed in Table 1 by 1 amino acid, HCDR2 comprising an amino acid sequence differing from an amino acid sequence listed in Table 1 by 1 amino acid, and HCDR3 comprising an amino acid sequence differing from an amino acid sequence listed in Table 1 by 1 amino acid. In certain embodiments, the present invention provides antibodies, or antigen-binding fragments thereof, comprising a HCVR and a LCVR, said LCVR comprising LCDR1 comprising an amino acid sequence differing from an amino acid sequence listed in Table 1 by 1 amino acid, LCDR2 comprising an amino acid sequence differing from an amino acid sequence listed in Table 1 by 1 amino acid, and LCDR3 comprising an amino acid sequence differing from an amino acid sequence listed in Table 1 by 1 amino acid. For example, the present invention provides anti-C5 antibodies, or antigen-binding fragments thereof, comprising a HCVR and a LCVR, said HCVR comprising HCDR1 comprising an amino acid sequence of SEQ ID NO: 100 or an amino acid sequence differing from SEQ ID NO: 100 by 1 amino acid, HCDR2 comprising an amino acid sequence of SEQ ID NO: 102 or an amino acid sequence differing from SEQ ID NO: 102 by 1 amino acid, and HCDR3 comprising an amino acid sequence of SEQ ID NO: 104 or an amino acid sequence differing from SEQ ID NO: 104 by 1 amino acid. In another exemplary embodiment, the present invention provides antibodies, or antigen-binding fragments thereof, comprising a HCVR and a LCVR,

said LCVR comprising LCDR1 comprising an amino acid sequence of SEQ ID NO: 108 or an amino acid sequence differing from SEQ ID NO: 108 by 1 amino acid, LCDR2 comprising an amino acid sequence of SEQ ID NO: 110 or an amino acid sequence differing from SEQ ID NO: 110 by 1 amino acid, and LCDR3 comprising an amino acid sequence of SEQ ID NO: 112 or an amino acid sequence differing from SEQ ID NO: 112 by 1 amino acid.

[021] The present invention provides antibodies, or antigen-binding fragments thereof, comprising a heavy chain comprising an amino acid sequence of SEQ ID NO: 353, or a substantially similar sequence thereof having at least 80%, at least 85%, at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[022] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a light chain comprising an amino acid sequence of SEQ ID NO: 354, or a substantially similar sequence thereof having at least 80%, at least 85%, at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[023] In certain embodiments, the present invention provides antibodies, or antigen-binding fragments thereof, comprising a heavy chain comprising an amino acid sequence of SEQ ID NO: 353, or a substantially similar sequence thereof having at least 80%, or at least 90% sequence identity thereto; and a light chain comprising an amino acid sequence of SEQ ID NO: 354, or a substantially similar sequence thereof having at least 80%, or at least 90% sequence identity thereto.

[024] The present invention also provides antibodies, or antigen-binding fragments thereof, comprising a set of six CDRs (*i.e.*, HCDR1-HCDR2-HCDR3-LCDR1-LCDR2-LCDR3) contained within any of the exemplary anti-C5 antibodies listed in Table 1. In certain embodiments, the HCDR1-HCDR2-HCDR3-LCDR1-LCDR2-LCDR3 amino acid sequence set is selected from the group consisting of SEQ ID NOs: 52-54-56-60-62-64 (*e.g.*, H4H12161P), 100-102-104-108-110-112 (*e.g.*, H4H12166P), 140-142-144-108-110-112 (*e.g.*, H4H12166P5), and 204-206-208-212-214-216 (*e.g.*, H4H12170P).

[025] In a related embodiment, the present invention provides antibodies, or antigen-binding fragments thereof, comprising a set of six CDRs (*i.e.*, HCDR1-HCDR2-HCDR3-LCDR1-LCDR2-LCDR3) contained within an HCVR/LCVR amino acid sequence pair as defined by any of the exemplary anti-C5 antibodies listed in Table 1. For example, the present invention includes antibodies, or antigen-binding fragments thereof, comprising the HCDR1-HCDR2-HCDR3-LCDR1-LCDR2-LCDR3 amino acid sequences set contained within an HCVR/LCVR amino acid sequence pair selected

from the group consisting of SEQ ID NOs: 50/58 (*e.g.*, H4H12161P), 98/106 (*e.g.*, H4H12166P), 138/106 (*e.g.*, H4H12166P5), or 202/210 (*e.g.*, H4H12170P). Methods and techniques for identifying CDRs within HCVR and LCVR amino acid sequences are well known in the art and can be used to identify CDRs within the specified HCVR and/or LCVR amino acid sequences disclosed herein. Exemplary conventions that can be used to identify the boundaries of CDRs include, *e.g.*, the Kabat definition, the Chothia definition, and the AbM definition. In general terms, the Kabat definition is based on sequence variability, the Chothia definition is based on the location of the structural loop regions, and the AbM definition is a compromise between the Kabat and Chothia approaches. *See, e.g.*, Kabat, "Sequences of Proteins of Immunological Interest," National Institutes of Health, Bethesda, Md. (1991); Al-Lazikani *et al.*, *J. Mol. Biol.* 273:927-948 (1997); and Martin *et al.*, *Proc. Natl. Acad. Sci. USA* 86:9268-9272 (1989). Public databases are also available for identifying CDR sequences within an antibody.

[026] In certain embodiments, the present invention includes an antibody or antigen-binding fragment thereof that binds specifically to C5, wherein the antibody or antigen-binding fragment thereof comprises three heavy chain complementarity determining regions (CDRs) (HCDR1, HCDR2 and HCDR3) contained within a heavy chain variable region (HCVR) and three light chain CDRs (LCDR1, LCDR2 and LCDR3) contained within a light chain variable region (LCVR), wherein the HCVR comprises: (i) the amino acid sequence of SEQ ID NO: 98, (ii) an amino acid sequence having at least 90% identity to SEQ ID NO: 98, (iii) an amino acid sequence having at least 95% identity to SEQ ID NO: 98; or (iv) the amino acid sequence of SEQ ID NO: 98 having no more than 5 amino acid substitutions; and the LCVR comprises: (i) the amino acid sequence of SEQ ID NO: 106, (ii) an amino acid sequence having at least 90% identity to SEQ ID NO: 106, (iii) an amino acid sequence having at least 95% identity to SEQ ID NO: 106; or (iv) the amino acid sequence of SEQ ID NO: 106 having no more than 5 amino acid substitutions.

[027] The present invention includes anti-C5 antibodies having a modified glycosylation pattern. In some embodiments, modification to remove undesirable glycosylation sites may be useful, or an antibody lacking a fucose moiety present on the oligosaccharide chain, for example, to increase antibody dependent cellular cytotoxicity (ADCC) function (see Shield *et al.* (2002) *JBC* 277:26733). In other applications,

modification of galactosylation can be made in order to modify complement dependent cytotoxicity (CDC).

[028] In certain embodiments, the present invention provides antibodies and antigen-binding fragments thereof that exhibit pH-dependent binding to C5. For example, the present invention includes antibodies and antigen-binding fragment thereof that bind C5 with higher affinity at neutral pH than at acidic pH (*i.e.*, reduced binding at acidic pH).

[029] In certain embodiments, the present invention provides antibodies and antigen-binding fragments that exhibit improved pharmacokinetic and pharmacodynamic properties, for example, the present invention provides anti-C5 antibodies that have extended serum half-life. In certain embodiments, the anti-C5 antibodies of the present invention have serum concentration of more than 10 µg/mL through day 40 in C5-humanized mice. In certain embodiments, the anti-C5 antibodies of the present invention block CP- and AP hemolysis through day 35 upon administration to C5-humanized mice.

[030] The present invention also provides for antibodies and antigen-binding fragments thereof that compete for specific binding to C5 with an antibody or antigen-binding fragment thereof comprising the CDRs of a HCVR and the CDRs of a LCVR, wherein the HCVR and LCVR each has an amino acid sequence selected from the HCVR and LCVR sequences listed in Table 1.

[031] The present invention also provides antibodies and antigen-binding fragments thereof that cross-compete for binding to C5 with a reference antibody or antigen-binding fragment thereof comprising the CDRs of a HCVR and the CDRs of a LCVR, wherein the HCVR and LCVR each has an amino acid sequence selected from the HCVR and LCVR sequences listed in Table 1.

[032] The present invention also provides antibodies and antigen-binding fragments thereof that bind to the same epitope as a reference antibody or antigen-binding fragment thereof comprising the CDRs of a HCVR and the CDRs of a LCVR, wherein the HCVR and LCVR each has an amino acid sequence selected from the HCVR and LCVR sequences listed in Table 1. In certain embodiments, the present invention provides antibodies and antigen-binding fragments thereof that bind to the same epitope as a reference antibody or antigen-binding fragment thereof comprising the CDRs of a HCVR and the CDRs of a LCVR, wherein the HCVR/LCVR amino acid sequence pair has SEQ ID NOs: 98/106.

[0333] The present invention also includes anti-C5 antibodies and antigen-binding fragments thereof that bind to one or more amino acid residues comprised in the alpha chain and/or the beta chain of C5. In certain embodiments, the present invention provides antibodies and antigen-binding fragments thereof that bind to one or more amino acids in the alpha chain of C5 and one or more amino acids in the beta chain of C5. In certain embodiments, the present invention provides antibodies and antigen-binding fragments thereof that bind to one or more amino acids in the alpha and beta chains of C5, wherein the antibodies do not bind to the C5a anaphylatoxin domain. In certain embodiments, the present invention provides anti-C5 antibodies that interact with one or more amino acids contained within human C5 (SEQ ID NO: 359). In certain embodiments, the present invention provides anti-C5 antibodies that interact with one or more amino acids contained within human C5 (SEQ ID NO: 359), wherein the antibodies do not bind to the C5a anaphylatoxin domain of C5. In certain embodiments, the present invention provides anti-C5 antibodies and antigen-binding fragments thereof that interact with an amino acid sequence selected from the group consisting of (a) amino acids 591 to 599 of SEQ ID NO: 359; (b) amino acids 593 to 599 of SEQ ID NO: 359; (c) amino acids 775 to 787 of SEQ ID NO: 359; (d) amino acids 775 to 794 of SEQ ID NO: 359; and (e) amino acids 779 to 787 of SEQ ID NO: 359. In certain embodiments, the present invention provides anti-C5 antibodies and antigen-binding fragments thereof that interact with one or more amino acids contained within SEQ ID NO: 359, for example, the present invention provides anti-C5 antibodies and antigen-binding fragments thereof that interact with at least 5 amino acids, at least 10 amino acids, or at least 15 amino acids contained within SEQ ID NO: 361. In certain embodiments, the present invention provides anti-C5 antibodies and antigen-binding fragments thereof that interact with one or more amino acids contained within SEQ ID NO: 359, for example, the present invention provides anti-C5 antibodies and antigen-binding fragments thereof that interact with at least 5 amino acids contained within SEQ ID NO: 360. In certain embodiments, the present invention provides anti-C5 antibodies and antigen-binding fragments thereof that interact with at least 5 amino acids contained within SEQ ID NOs: 360 and 361. In certain embodiments, the present invention provides anti-C5 antibodies and antigen-binding fragments thereof that interact with the amino acid sequence of SEQ ID NO: 360 (corresponding to amino acids 591 to 599 of SEQ ID NO: 359) and with the amino acid sequence of SEQ ID NO: 361 (corresponding to amino acids 775 to 794 of SEQ ID NO: 359).

[034] In some embodiments, the antibody or antigen binding fragment thereof may bind specifically to C5 in an agonist manner, i.e., it may enhance or stimulate C5 binding and/or activity; in other embodiments, the antibody may bind specifically to C5 in an antagonist manner, i.e., it may block C5 binding and/or activity.

[035] The present invention also provides isolated antibodies and antigen-binding fragments thereof that block C5 binding to C5 convertase. In some embodiments, the antibody or antigen-binding fragment thereof that blocks C5 binding to C5 convertase may bind to the same epitope on C5 as C5 convertase or may bind to a different epitope on C5 as C5 convertase. In some embodiments, the present invention provides antibodies or antigen-binding fragments thereof that block the binding of C5 to monkey C5 convertase.

[036] In certain embodiments, the antibodies or antigen-binding fragments of the present invention are bispecific comprising a first binding specificity to a first epitope of C5 protein and a second binding specificity to a second epitope of C5 protein wherein the first and second epitopes are distinct and non-overlapping.

[037] In certain embodiments, the antibodies and antigen-binding fragments of the present invention bind to C5a with an IC_{50} of less than 0.5nM. In certain embodiments, the antibodies comprise an HCVR comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 290, 306, 322, and 338. In certain embodiments, the antibodies comprise an LCVR comprising an amino acid sequence selected from the group consisting of SEQ ID NOs: 298, 314, 330, and 346.

[038] In certain embodiments, the present invention provides an isolated antibody or antigen-binding fragment thereof that has one or more of the following characteristics: (a) is a fully human monoclonal antibody; (b) binds to human C5 with a dissociation constant (K_D) of less than 0.9nM at 25°C, as measured in a surface plasmon resonance assay; (c) binds to human C5 with a K_D of less than 0.3nM at 37°C, as measured in a surface plasmon resonance assay; (d) binds to monkey C5 with a K_D of less than 65nM, as measured in a surface plasmon resonance assay; (e) binds to human C5 variant R885H (SEQ ID NO: 356) with a K_D of less than 0.5nM, as measured in a surface plasmon resonance assay; (f) binds to human C5 variant R885C (SEQ ID NO: 357) with a K_D of less than 0.5nM, as measured in a surface plasmon resonance assay; (g) blocks human C5-mediated classical pathway (CP) hemolysis by more than 95% and with IC_{50} less than 6nM, as measured in a CP hemolysis assay; (h) blocks human C5-mediated alternative pathway (AP) hemolysis by more than 70% and with IC_{50} less

than 165nM, as measured in a AP hemolysis assay; (i) inhibits African green monkey C5-mediated CP hemolysis with IC_{50} less than 185nM, as measured in a CP hemolysis assay; (j) inhibits African green monkey C5-mediated AP hemolysis with IC_{50} less than 235nM, as measured in a AP hemolysis assay; (k) inhibits cynomolgus monkey C5-mediated CP hemolysis with IC_{50} less than 145nM, as measured in a CP hemolysis assay; and (l) inhibits cynomolgus monkey C5-mediated AP hemolysis with IC_{50} less than 30nM, as measured in a AP hemolysis assay.

[039] In certain embodiments, the present invention provides an isolated recombinant monoclonal anti-C5 antibody or antigen-binding fragment thereof that has one or more of the following characteristics: (a) comprises a set of six CDRs comprising the amino acid sequences of SEQ ID NOs: 100-102-104-108-110-112; (b) binds to human C5 with a dissociation constant (K_D) of less than 0.2nM at 25°C, as measured in a surface plasmon resonance assay; (c) binds to human C5 with a K_D of less than 0.3nM at 37°C, as measured in a surface plasmon resonance assay; (d) binds to a human C5 variant (R885H) with a K_D of less than 0.4nM at 37°C, as measured in a surface plasmon resonance assay; (e) inhibits classical pathway (CP)-mediated hemolysis of human serum with an IC_{50} of less than 3nM; (f) inhibits alternative pathway (AP)-mediated hemolysis of human serum with an IC_{50} of less than 27nM; (g) inhibits CP-mediated hemolysis of monkey serum with an IC_{50} of less than 21nM; (g) inhibits AP-mediated hemolysis of monkey serum with an IC_{50} of less than 10nM; (h) has serum half-life ($t_{1/2}$) of more than 10 days in C5-humanized mice; (i) has serum concentration of more than 10 µg/mL through day 40 upon administering to C5-humanized mice; (j) blocks CP-mediated hemolysis through day 50 in C5-humanized mice; and (k) binds to one or more amino acids comprised in the alpha chain and/or the beta chain of SEQ ID NO: 359, wherein the antibody does not bind to the C5a anaphylatoxin domain of C5.

[040] In a second aspect, the present invention provides nucleic acid molecules encoding anti-C5 antibodies or portions thereof. For example, the present invention provides nucleic acid molecules encoding any of the HCVR amino acid sequences listed in Table 1; in certain embodiments the nucleic acid molecule comprises a polynucleotide sequence selected from any of the HCVR nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[041] The present invention also provides nucleic acid molecules encoding any of the LCVR amino acid sequences listed in Table 1; in certain embodiments the nucleic acid

molecule comprises a polynucleotide sequence selected from any of the LCVR nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[042] The present invention also provides nucleic acid molecules encoding any of the HCDR1 amino acid sequences listed in Table 1; in certain embodiments the nucleic acid molecule comprises a polynucleotide sequence selected from any of the HCDR1 nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[043] The present invention also provides nucleic acid molecules encoding any of the HCDR2 amino acid sequences listed in Table 1; in certain embodiments the nucleic acid molecule comprises a polynucleotide sequence selected from any of the HCDR2 nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[044] The present invention also provides nucleic acid molecules encoding any of the HCDR3 amino acid sequences listed in Table 1; in certain embodiments the nucleic acid molecule comprises a polynucleotide sequence selected from any of the HCDR3 nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[045] The present invention also provides nucleic acid molecules encoding any of the LCDR1 amino acid sequences listed in Table 1; in certain embodiments the nucleic acid molecule comprises a polynucleotide sequence selected from any of the LCDR1 nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[046] The present invention also provides nucleic acid molecules encoding any of the LCDR2 amino acid sequences listed in Table 1; in certain embodiments the nucleic acid molecule comprises a polynucleotide sequence selected from any of the LCDR2 nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[047] The present invention also provides nucleic acid molecules encoding any of the LCDR3 amino acid sequences listed in Table 1; in certain embodiments the nucleic acid molecule comprises a polynucleotide sequence selected from any of the LCDR3 nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto.

[048] The present invention also provides nucleic acid molecules encoding an HCVR, wherein the HCVR comprises a set of three CDRs (*i.e.*, HCDR1-HCDR2-HCDR3), wherein the HCDR1-HCDR2-HCDR3 amino acid sequence set is as defined by any of the exemplary anti-C5 antibodies listed in Table 1.

[049] The present invention also provides nucleic acid molecules encoding an LCVR, wherein the LCVR comprises a set of three CDRs (*i.e.*, LCDR1-LCDR2-LCDR3), wherein the LCDR1-LCDR2-LCDR3 amino acid sequence set is as defined by any of the exemplary anti-C5 antibodies listed in Table 1.

[050] The present invention also provides nucleic acid molecules encoding both an HCVR and an LCVR, wherein the HCVR comprises an amino acid sequence of any of the HCVR amino acid sequences listed in Table 1, and wherein the LCVR comprises an amino acid sequence of any of the LCVR amino acid sequences listed in Table 1. In certain embodiments, the nucleic acid molecule comprises a polynucleotide sequence selected from any of the HCVR nucleic acid sequences listed in Table 2, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto, and a polynucleotide sequence selected from any of the LCVR nucleic acid sequences listed in Table 1, or a substantially similar sequence thereof having at least 90%, at least 95%, at least 98% or at least 99% sequence identity thereto. In certain embodiments according to this aspect of the invention, the nucleic acid molecule encodes an HCVR and LCVR, wherein the HCVR and LCVR are both derived from the same anti-C5 antibody listed in Table 1.

[051] In a related aspect, the present invention provides recombinant expression vectors capable of expressing a polypeptide comprising a heavy or light chain variable region of an anti-C5 antibody. For example, the present invention includes recombinant expression vectors comprising any of the nucleic acid molecules mentioned above, *i.e.*, nucleic acid molecules encoding any of the HCVR, LCVR, and/or CDR sequences as set forth in Table 2. Also included within the scope of the present invention are host cells into which such vectors have been introduced, as well as methods of producing

the antibodies or portions thereof by culturing the host cells under conditions permitting production of the antibodies or antibody fragments, and recovering the antibodies and antibody fragments so produced.

[052] In a third aspect, the invention provides a pharmaceutical composition comprising a therapeutically effective amount of at least one recombinant monoclonal antibody or antigen-binding fragment thereof which specifically binds C5 and a pharmaceutically acceptable carrier. In a related aspect, the invention features a composition which is a combination of an anti-C5 antibody and a second therapeutic agent. In one embodiment, the second therapeutic agent is any agent that is advantageously combined with an anti-C5 antibody. Exemplary agents that may be advantageously combined with an anti-C5 antibody include, without limitation, other agents that bind and/or inhibit C5 activity (including other antibodies or antigen-binding fragments thereof, etc.) and/or agents which do not directly bind C5 but nonetheless treat or ameliorate at least one symptom or indication of a C5-associated disease or disorder. Additional combination therapies and co-formulations involving the anti-C5 antibodies of the present invention are disclosed elsewhere herein.

[053] In a fourth aspect, the invention provides therapeutic methods for treating a disease or disorder associated with C5 in a subject using an anti-C5 antibody or antigen-binding portion of an antibody of the invention, wherein the therapeutic methods comprise administering a therapeutically effective amount of a pharmaceutical composition comprising an antibody or antigen-binding fragment of an antibody of the invention to the subject in need thereof. The disorder treated is any disease or condition which is improved, ameliorated, inhibited or prevented by inhibition of C5 activity. In certain embodiments, the invention provides methods to prevent, treat or ameliorate at least one symptom of atypical hemolytic uremic syndrome (aHUS), the method comprising administering a therapeutically effective amount of an anti-C5 antibody or antigen-binding fragment thereof of the invention to a subject in need thereof. In some embodiments, the present invention provides methods to ameliorate or reduce the severity of at least one symptom or indication of paroxysmal nocturnal hemoglobinuria (PNH) in a subject by administering an anti-C5 antibody of the invention. In some embodiments, the antibody or antigen-binding fragment thereof may be administered prophylactically or therapeutically to a subject having or at risk of having a C5-associated disease or disorder. In certain embodiments, the antibody or antigen-binding fragment thereof of the invention is administered in combination with a

second therapeutic agent to the subject in need thereof. The second therapeutic agent may be selected from the group consisting of an anti-inflammatory drug (such as corticosteroids, and non-steroidal anti-inflammatory drugs), a different antibody to C5 protein, a dietary supplement such as anti-oxidants and any other drug or therapy known in the art. In certain embodiments, the second therapeutic agent may be an agent that helps to counteract or reduce any possible side effect(s) associated with an antibody or antigen-binding fragment thereof of the invention, if such side effect(s) should occur. The antibody or fragment thereof may be administered subcutaneously, intravenously, intradermally, intraperitoneally, orally, or intramuscularly. The antibody or fragment thereof may be administered at a dose of about 0.1 mg/kg of body weight to about 100 mg/kg of body weight of the subject. In certain embodiments, an antibody of the present invention may be administered at one or more doses comprising between 50mg to 600mg.

[054] The present invention also includes use of an anti-C5 antibody or antigen-binding fragment thereof of the invention in the manufacture of a medicament for the treatment of a disease or disorder that would benefit from the blockade of C5 binding and/or activity.

[055] Other embodiments will become apparent from a review of the ensuing detailed description.

BRIEF DESCRIPTION OF THE FIGURES

[056] **Figure 1** shows inhibition of C5a levels by anti-C5 antibody H4H12166P in a dose-dependent manner, as determined by ELISA (described in Example 9 herein).

[057] **Figure 2** shows total serum concentration vs. time following a single 15 mg/kg intravenous injection of H4H12166P, H4H12161P, or Comparator 2 to male cynomolgus monkeys (described in Example 10 herein). Concentration-time profiles were plotted through the first post dose below the limit of quantitation (BLQ) result, if applicable, which was imputed as LLOQ/2. Each data point represents Mean ($\pm$ SD) (n = 4 animals/group); concentrations considered to be impacted by ADA were excluded from 1 animal in the H4H12166P group and 1 animal in the H4H12161P group starting at Day 36 and Day 29, respectively. LLOQ = Lower limit of quantification

[058] **Figure 3** shows percent hemolysis vs. time in ex vivo red blood cell **(A)** Classical Pathway and **(B)** Alternative Pathway assays following a single intravenous injection of H4H12166P, H4H12161P or Comparator 2 to male cynomolgus monkeys. %

hemolysis, calculated as a ratio of experimental vs. maximal lysis with % background lysis subtracted from both values, is related to the amount of C5 inhibited by the particular anti-C5 antibody present in the serum at a given time point. Each data point represents Mean ($\pm$ SD).

[059] **Figure 4** shows total serum concentration vs. time profiles of selected anti-C5 antibodies in mice humanized for C5 (described in Example 11 herein). Humanized C5 mice were administered a single 15 mg/kg subcutaneous dose of H4H12166P, Comparator 1 or Comparator 2. Each data point represents the mean $\pm$ s.e.m. (n =4-5 each). Antibody concentrations in sera were monitored 1, 10, 20, 30 and 40 days post injection using a sandwich ELISA.

[060] **Figure 5** shows percent hemolysis vs. time in an ex vivo complement classical pathway hemolysis assay of selected anti-C5 antibodies in mice humanized for C5. Humanized C5 mice were administered a single 15 mg/kg subcutaneous dose of H4H12166P, Comparator 1 or Comparator 2. Each data point represents the mean $\pm$ s.e.m. (n =4-5 each). The percent hemolysis in serum was monitored at predose, 10, 20, 30, 40 and 50 days post injection. % hemolysis, calculated as a ratio of experimental vs. maximal lysis with % background lysis subtracted from both values, is related to the amount of C5 inhibited by the particular anti-C5 antibody present in the serum at a given time point.

[061] **Figure 6** shows total serum concentration vs. time profiles of selected anti-C5 antibodies in mice humanized for C5 (described in Example 11 herein). Mice were administered a single 15 mg/kg subcutaneous dose of H4H12166P, H4H12161P, Comparator 1 or IgG4^P isotype control. Each data point represents the mean $\pm$ s.e.m. (n = 5 each). Antibody levels in sera were monitored 6 hours, 1, 2, 3, 4, 7, 10, 14, 21, 30, 45 and 59 days post injection using a sandwich ELISA.

[062] **Figure 7** is a graph showing optical coherence tomography (OCT) scores in mice treated with isotype control or with anti-C5 antibody M1M17628N at 10 mg/kg or 50 mg/kg (described in Example 14 herein). ****p<0.0001, two-way ANOVA treatment with anti-C5 antibody at 50 mg/kg vs. no treatment or treatment with isotype control.

[063] **Figure 8** shows inhibition of classical pathway hemolysis by anti-C5 antibody M1M17628N in the absence of C3 (**A**); and in the presence of 80 μ g/mL of human C3 (**B**) (described in Example 14 herein).

[064] Figure 9 shows cell cluster count in C5 humanized mice treated with isotype control or with anti-human C5 antibody H4H12170P at 10 mg/kg or 50 mg/kg (described in Example 15 herein). n=8-12 eyes for each group

[065] Figure 10 is a graph showing OCT scores in C5 humanized mice treated with isotype control or with anti-human C5 antibody H4H12170P at 10 mg/kg or 50 mg/kg (described in Example 15 herein). n=8-12 eyes for each group

[066] Figure 11 is a graph showing OCT scores in C5 humanized mice treated with isotype control, anti-human C5 antibody H4H12166P at 3 mg/kg or 10 mg/kg, or Comparator 2 at 10 mg/kg. n=6-12 eyes for each group (described in Example 15 herein).

[067] Figure 12 shows cell cluster count in C5 humanized mice treated with isotype control, anti-human C5 antibody H4H12166P at 3 mg/kg or 10 mg/kg, or Comparator 2 at 10 mg/kg. n=6-12 eyes for each group (described in Example 15 herein).

[068] Figure 13 is a survival curve of NZBWF1 mice treated with isotype control or with anti-C5 antibodies M1M17628N or M1M17627N (described in Example 17 herein).

[069] Figure 14 shows levels of (A) urinary albumin and (B) urinary albumin normalized to urinary creatinine in NZBWF1 mice treated with isotype control or with anti-C5 antibodies M1M17628N or M1M17627N (described in Example 17 herein).

[070] Figure 15 shows levels of blood urea nitrogen in NZBWF1 mice treated with isotype control or with anti-C5 antibodies M1M17628N or M1M17627N (described in Example 17 herein).

[071] Figure 16 is a graph showing inhibition of antibody-dependent cytotoxicity of astrocytes by anti-C5 antibodies H4H12166P, H4H12170P, Comparator 1 and Comparator 2, as described in Example 18.

DETAILED DESCRIPTION

[072] Before the present methods are described, it is to be understood that this invention is not limited to particular methods, and experimental conditions described, as such methods and conditions may vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims.

[073] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, preferred methods and materials are now described. All publications mentioned herein are incorporated herein by reference in their entirety.

Definitions

[074] The term “C5”, also called “complement component 5” or “complement factor 5” refers to the serum protein of the complement cascade. The C5 protein is a 1676 amino acid protein comprising two chains, alpha and beta. The protein represents the convergence point for three complement activation pathways: classical pathway, alternative pathway and the mannose binding lectin pathway. The amino acid sequence of full-length C5 protein is exemplified by the amino acid sequence provided in GenBank as accession number NP_001726.2 (SEQ ID NO: 355). The term “C5” includes recombinant C5 protein or a fragment thereof. The term also encompasses C5 protein or a fragment thereof coupled to, for example, histidine tag, mouse or human Fc, or a signal sequence such as ROR1. For example, the term includes sequences exemplified by the sequence shown in SEQ ID NO: 356 or 357, comprising a histidine tag at the C-terminal, coupled to amino acid residues 19 – 1676 of full-length C5 protein. The term also includes protein variants that comprise a histidine tag at the C-terminal, coupled to amino acid residues 19 – 1676 of full-length C5 protein with a R885H change or a R885C change.

[075] The term "antibody", as used herein, is intended to refer to immunoglobulin molecules comprised of four polypeptide chains, two heavy (H) chains and two light (L) chains inter-connected by disulfide bonds (*i.e.*, "full antibody molecules"), as well as multimers thereof (*e.g.* IgM) or antigen-binding fragments thereof. Each heavy chain is comprised of a heavy chain variable region (“HCVR” or “V_H”) and a heavy chain constant region (comprised of domains C_{H1}, C_{H2} and C_{H3}). Each light chain is comprised of a light chain variable region (“LCVR or “V_L”) and a light chain constant region (C_L). The V_H and V_L regions can be further subdivided into regions of hypervariability, termed complementarity determining regions (CDR), interspersed with regions that are more conserved, termed framework regions (FR). Each V_H and V_L is composed of three CDRs and four FRs, arranged from amino-terminus to

carboxy-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, FR4. In certain embodiments of the invention, the FRs of the antibody (or antigen binding fragment thereof) may be identical to the human germline sequences, or may be naturally or artificially modified. An amino acid consensus sequence may be defined based on a side-by-side analysis of two or more CDRs.

[076] Substitution of one or more CDR residues or omission of one or more CDRs is also possible. Antibodies have been described in the scientific literature in which one or two CDRs can be dispensed with for binding. Padlan *et al.* (1995 FASEB J. 9:133-139) analyzed the contact regions between antibodies and their antigens, based on published crystal structures, and concluded that only about one fifth to one third of CDR residues actually contact the antigen. Padlan also found many antibodies in which one or two CDRs had no amino acids in contact with an antigen (see also, Vajdos *et al.* 2002 J Mol Biol 320:415-428).

[077] CDR residues not contacting antigen can be identified based on previous studies (for example residues H60-H65 in CDRH2 are often not required), from regions of Kabat CDRs lying outside Chothia CDRs, by molecular modeling and/or empirically. If a CDR or residue(s) thereof is omitted, it is usually substituted with an amino acid occupying the corresponding position in another human antibody sequence or a consensus of such sequences. Positions for substitution within CDRs and amino acids to substitute can also be selected empirically. Empirical substitutions can be conservative or non-conservative substitutions.

[078] The fully human anti-C5 monoclonal antibodies disclosed herein may comprise one or more amino acid substitutions, insertions and/or deletions in the framework and/or CDR regions of the heavy and light chain variable domains as compared to the corresponding germline sequences. Such mutations can be readily ascertained by comparing the amino acid sequences disclosed herein to germline sequences available from, for example, public antibody sequence databases. The present invention includes antibodies, and antigen-binding fragments thereof, which are derived from any of the amino acid sequences disclosed herein, wherein one or more amino acids within one or more framework and/or CDR regions are mutated to the corresponding residue(s) of the germline sequence from which the antibody was derived, or to the corresponding residue(s) of another human germline sequence, or to a conservative amino acid substitution of the corresponding germline residue(s) (such sequence changes are referred to herein collectively as "germline mutations"). A person of ordinary skill in

the art, starting with the heavy and light chain variable region sequences disclosed herein, can easily produce numerous antibodies and antigen-binding fragments which comprise one or more individual germline mutations or combinations thereof. In certain embodiments, all of the framework and/or CDR residues within the V_H and/or V_L domains are mutated back to the residues found in the original germline sequence from which the antibody was derived. In other embodiments, only certain residues are mutated back to the original germline sequence, *e.g.*, only the mutated residues found within the first 8 amino acids of FR1 or within the last 8 amino acids of FR4, or only the mutated residues found within CDR1, CDR2 or CDR3. In other embodiments, one or more of the framework and/or CDR residue(s) are mutated to the corresponding residue(s) of a different germline sequence (*i.e.*, a germline sequence that is different from the germline sequence from which the antibody was originally derived). Furthermore, the antibodies of the present invention may contain any combination of two or more germline mutations within the framework and/or CDR regions, *e.g.*, wherein certain individual residues are mutated to the corresponding residue of a particular germline sequence while certain other residues that differ from the original germline sequence are maintained or are mutated to the corresponding residue of a different germline sequence. Once obtained, antibodies and antigen-binding fragments that contain one or more germline mutations can be easily tested for one or more desired property such as, improved binding specificity, increased binding affinity, improved or enhanced antagonistic or agonistic biological properties (as the case may be), reduced immunogenicity, etc. Antibodies and antigen-binding fragments obtained in this general manner are encompassed within the present invention.

[079] The present invention also includes fully human anti-C5 monoclonal antibodies comprising variants of any of the HCVR, LCVR, and/or CDR amino acid sequences disclosed herein having one or more conservative substitutions. For example, the present invention includes anti-C5 antibodies having HCVR, LCVR, and/or CDR amino acid sequences with, *e.g.*, 10 or fewer, 8 or fewer, 6 or fewer, 4 or fewer, etc. conservative amino acid substitutions relative to any of the HCVR, LCVR, and/or CDR amino acid sequences disclosed herein.

[080] The term "human antibody", as used herein, is intended to include antibodies having variable and constant regions derived from human germline immunoglobulin sequences. The human mAbs of the invention may include amino acid residues not encoded by human germline immunoglobulin sequences (*e.g.*, mutations introduced by

random or site-specific mutagenesis *in vitro* or by somatic mutation *in vivo*), for example in the CDRs and in particular CDR3. However, the term "human antibody", as used herein, is not intended to include mAbs in which CDR sequences derived from the germline of another mammalian species (*e.g.*, mouse), have been grafted onto human FR sequences. The term includes antibodies recombinantly produced in a non-human mammal, or in cells of a non-human mammal. The term is not intended to include antibodies isolated from or generated in a human subject.

[081] The term "recombinant", as used herein, refers to antibodies or antigen-binding fragments thereof of the invention created, expressed, isolated or obtained by technologies or methods known in the art as recombinant DNA technology which include, *e.g.*, DNA splicing and transgenic expression. The term refers to antibodies expressed in a non-human mammal (including transgenic non-human mammals, *e.g.*, transgenic mice), or a cell (*e.g.*, CHO cells) expression system or isolated from a recombinant combinatorial human antibody library.

[082] The term "specifically binds," or "binds specifically to", or the like, means that an antibody or antigen-binding fragment thereof forms a complex with an antigen that is relatively stable under physiologic conditions. Specific binding can be characterized by an equilibrium dissociation constant of at least about 1×10^{-8} M or less (*e.g.*, a smaller K_D denotes a tighter binding). Methods for determining whether two molecules specifically bind are well known in the art and include, for example, equilibrium dialysis, surface plasmon resonance, and the like. As described herein, antibodies have been identified by surface plasmon resonance, *e.g.*, BIACORE™, which bind specifically to C5. Moreover, multi-specific antibodies that bind to one domain in C5 and one or more additional antigens or a bi-specific that binds to two different regions of C5 are nonetheless considered antibodies that "specifically bind", as used herein.

[083] The term "high affinity" antibody refers to those mAbs having a binding affinity to C5, expressed as K_D , of at least 10^{-8} M; preferably 10^{-9} M; more preferably 10^{-10} M, even more preferably 10^{-11} M, even more preferably 10^{-12} M, as measured by surface plasmon resonance, *e.g.*, BIACORE™ or solution-affinity ELISA.

[084] By the term "slow off rate", "Koff" or "kd" is meant an antibody that dissociates from C5, with a rate constant of $1 \times 10^{-3} \text{ s}^{-1}$ or less, preferably $1 \times 10^{-4} \text{ s}^{-1}$ or less, as determined by surface plasmon resonance, *e.g.*, BIACORE™.

[085] The terms "antigen-binding portion" of an antibody, "antigen-binding fragment" of an antibody, and the like, as used herein, include any naturally occurring,

enzymatically obtainable, synthetic, or genetically engineered polypeptide or glycoprotein that specifically binds an antigen to form a complex. The terms "antigen-binding fragment" of an antibody, or "antibody fragment", as used herein, refers to one or more fragments of an antibody that retain the ability to bind to C5 protein.

[086] In specific embodiments, antibody or antibody fragments of the invention may be conjugated to a moiety such a ligand or a therapeutic moiety ("immunoconjugate"), a second anti-C5 antibody, or any other therapeutic moiety useful for treating a C5-associated disease or disorder.

[087] An "isolated antibody", as used herein, is intended to refer to an antibody that is substantially free of other antibodies (Abs) having different antigenic specificities (*e.g.*, an isolated antibody that specifically binds C5, or a fragment thereof, is substantially free of Abs that specifically bind antigens other than C5.

[088] A "blocking antibody" or a "neutralizing antibody", as used herein (or an "antibody that neutralizes C5 activity" or "antagonist antibody"), is intended to refer to an antibody whose binding to C5 results in inhibition of at least one biological activity of C5. For example, an antibody of the invention may prevent or block complement-mediated hemolysis by classical pathway or alternative pathway.

[089] The term "surface plasmon resonance", as used herein, refers to an optical phenomenon that allows for the analysis of real-time biomolecular interactions by detection of alterations in protein concentrations within a biosensor matrix, for example using the BIACORE™ system (Pharmacia Biosensor AB, Uppsala, Sweden and Piscataway, N.J.).

[090] The term " K_D ", as used herein, is intended to refer to the equilibrium dissociation constant of a particular antibody-antigen interaction.

[091] The term "epitope" refers to an antigenic determinant that interacts with a specific antigen binding site in the variable region of an antibody molecule known as a paratope. A single antigen may have more than one epitope. Thus, different antibodies may bind to different areas on an antigen and may have different biological effects. The term "epitope" also refers to a site on an antigen to which B and/or T cells respond. It also refers to a region of an antigen that is bound by an antibody. Epitopes may be defined as structural or functional. Functional epitopes are generally a subset of the structural epitopes and have those residues that directly contribute to the affinity of the interaction. Epitopes may also be conformational, that is, composed of non-linear amino acids. In certain embodiments, epitopes may include determinants that are

chemically active surface groupings of molecules such as amino acids, sugar side chains, phosphoryl groups, or sulfonyl groups, and, in certain embodiments, may have specific three-dimensional structural characteristics, and/or specific charge characteristics.

[092] The term “cross-competes”, as used herein, means an antibody or antigen-binding fragment thereof binds to an antigen and inhibits or blocks the binding of another antibody or antigen-binding fragment thereof. The term also includes competition between two antibodies in both orientations, *i.e.*, a first antibody that binds and blocks binding of second antibody and vice-versa. In certain embodiments, the first antibody and second antibody may bind to the same epitope. Alternatively, the first and second antibodies may bind to different, but overlapping epitopes such that binding of one inhibits or blocks the binding of the second antibody, *e.g.*, *via* steric hindrance. Cross-competition between antibodies may be measured by methods known in the art, for example, by a real-time, label-free bio-layer interferometry assay. Cross-competition between two antibodies may be expressed as the binding of the second antibody that is less than the background signal due to self-self binding (wherein first and second antibodies is the same antibody). Cross-competition between 2 antibodies may be expressed, for example, as % binding of the second antibody that is less than the baseline self-self background binding (wherein first and second antibodies is the same antibody).

[093] The term "substantial identity" or "substantially identical," when referring to a nucleic acid or fragment thereof, indicates that, when optimally aligned with appropriate nucleotide insertions or deletions with another nucleic acid (or its complementary strand), there is nucleotide sequence identity in at least about 90%, and more preferably at least about 95%, 96%, 97%, 98% or 99% of the nucleotide bases, as measured by any well-known algorithm of sequence identity, such as FASTA, BLAST or GAP, as discussed below. A nucleic acid molecule having substantial identity to a reference nucleic acid molecule may, in certain instances, encode a polypeptide having the same or substantially similar amino acid sequence as the polypeptide encoded by the reference nucleic acid molecule.

[094] As applied to polypeptides, the term "substantial similarity" or “substantially similar” means that two peptide sequences, when optimally aligned, such as by the programs GAP or BESTFIT using default gap weights, share at least 90% sequence identity, even more preferably at least 95%, 98% or 99% sequence identity. Preferably,

residue positions, which are not identical, differ by conservative amino acid substitutions. A "conservative amino acid substitution" is one in which an amino acid residue is substituted by another amino acid residue having a side chain (R group) with similar chemical properties (*e.g.*, charge or hydrophobicity). In general, a conservative amino acid substitution will not substantially change the functional properties of a protein. In cases where two or more amino acid sequences differ from each other by conservative substitutions, the percent or degree of similarity may be adjusted upwards to correct for the conservative nature of the substitution. Means for making this adjustment are well known to those of skill in the art. See, *e.g.*, Pearson (1994) *Methods Mol. Biol.* 24: 307-331, which is herein incorporated by reference. Examples of groups of amino acids that have side chains with similar chemical properties include 1) aliphatic side chains: glycine, alanine, valine, leucine and isoleucine; 2) aliphatic-hydroxyl side chains: serine and threonine; 3) amide-containing side chains: asparagine and glutamine; 4) aromatic side chains: phenylalanine, tyrosine, and tryptophan; 5) basic side chains: lysine, arginine, and histidine; 6) acidic side chains: aspartate and glutamate, and 7) sulfur-containing side chains: cysteine and methionine. Preferred conservative amino acids substitution groups are: valine-leucine-isoleucine, phenylalanine-tyrosine, lysine-arginine, alanine-valine, glutamate-aspartate, and asparagine-glutamine. Alternatively, a conservative replacement is any change having a positive value in the PAM250 log-likelihood matrix disclosed in Gonnet *et al.* (1992) *Science* 256: 1443-45, herein incorporated by reference. A "moderately conservative" replacement is any change having a nonnegative value in the PAM250 log-likelihood matrix.

[095] Sequence similarity for polypeptides is typically measured using sequence analysis software. Protein analysis software matches similar sequences using measures of similarity assigned to various substitutions, deletions and other modifications, including conservative amino acid substitutions. For instance, GCG software contains programs such as GAP and BESTFIT which can be used with default parameters to determine sequence homology or sequence identity between closely related polypeptides, such as homologous polypeptides from different species of organisms or between a wild type protein and a mutein thereof. See, *e.g.*, GCG Version 6.1. Polypeptide sequences also can be compared using FASTA with default or recommended parameters; a program in GCG Version 6.1. FASTA (*e.g.*, FASTA2 and FASTA3) provides alignments and percent sequence identity of the regions of the best

overlap between the query and search sequences (Pearson (2000) *supra*). Another preferred algorithm when comparing a sequence of the invention to a database containing a large number of sequences from different organisms is the computer program BLAST, especially BLASTP or TBLASTN, using default parameters. See, e.g., Altschul *et al.* (1990) J. Mol. Biol. 215: 403-410 and (1997) Nucleic Acids Res. 25:3389-3402, each of which is herein incorporated by reference.

[096] By the phrase “therapeutically effective amount” is meant an amount that produces the desired effect for which it is administered. The exact amount will depend on the purpose of the treatment, and will be ascertainable by one skilled in the art using known techniques (see, for example, Lloyd (1999) *The Art, Science and Technology of Pharmaceutical Compounding*).

[097] As used herein, the term “subject” refers to an animal, preferably a mammal, more preferably a human, in need of amelioration, prevention and/or treatment of a C5-associated disease or disorder such as atypical hemolytic uremic syndrome (aHUS) or paroxysmal nocturnal hemoglobinuria (PNH). The term includes human subjects who have or are at risk of having such a disease or disorder.

[098] As used herein, the terms “treat”, “treating”, or “treatment” refer to the reduction or amelioration of the severity of at least one symptom or indication of a C5-associated disease or disorder due to the administration of a therapeutic agent such as an antibody of the present invention to a subject in need thereof. The terms include inhibition of progression of disease or of worsening of a symptom/indication. The terms also include positive prognosis of disease, i.e., the subject may be free of disease or may have reduced disease upon administration of a therapeutic agent such as an antibody of the present invention. The therapeutic agent may be administered at a therapeutic dose to the subject.

[099] The terms “prevent”, “preventing” or “prevention” refer to inhibition of manifestation of a C5-associated disease or disorder or any symptoms or indications of such a disease or disorder upon administration of an antibody of the present invention.

Antigen-Binding Fragments of Antibodies

[0100] Unless specifically indicated otherwise, the term “antibody,” as used herein, shall be understood to encompass antibody molecules comprising two immunoglobulin heavy chains and two immunoglobulin light chains (*i.e.*, “full antibody molecules”) as well as antigen-binding fragments thereof. The terms “antigen-binding portion” of an

antibody, "antigen-binding fragment" of an antibody, and the like, as used herein, include any naturally occurring, enzymatically obtainable, synthetic, or genetically engineered polypeptide or glycoprotein that specifically binds an antigen to form a complex. The terms "antigen-binding fragment" of an antibody, or "antibody fragment", as used herein, refers to one or more fragments of an antibody that retain the ability to specifically bind to C5 protein. An antibody fragment may include a Fab fragment, a F(ab')₂ fragment, a Fv fragment, a dAb fragment, a fragment containing a CDR, or an isolated CDR. In certain embodiments, the term "antigen-binding fragment" refers to a polypeptide fragment of a multi-specific antigen-binding molecule. Antigen-binding fragments of an antibody may be derived, *e.g.*, from full antibody molecules using any suitable standard techniques such as proteolytic digestion or recombinant genetic engineering techniques involving the manipulation and expression of DNA encoding antibody variable and (optionally) constant domains. Such DNA is known and/or is readily available from, *e.g.*, commercial sources, DNA libraries (including, *e.g.*, phage-antibody libraries), or can be synthesized. The DNA may be sequenced and manipulated chemically or by using molecular biology techniques, for example, to arrange one or more variable and/or constant domains into a suitable configuration, or to introduce codons, create cysteine residues, modify, add or delete amino acids, etc.

[0101] Non-limiting examples of antigen-binding fragments include: (i) Fab fragments; (ii) F(ab')₂ fragments; (iii) Fd fragments; (iv) Fv fragments; (v) single-chain Fv (scFv) molecules; (vi) dAb fragments; and (vii) minimal recognition units consisting of the amino acid residues that mimic the hypervariable region of an antibody (*e.g.*, an isolated complementarity determining region (CDR) such as a CDR3 peptide), or a constrained FR3-CDR3-FR4 peptide. Other engineered molecules, such as domain-specific antibodies, single domain antibodies, domain-deleted antibodies, chimeric antibodies, CDR-grafted antibodies, diabodies, triabodies, tetrabodies, minibodies, nanobodies (*e.g.* monovalent nanobodies, bivalent nanobodies, etc.), small modular immunopharmaceuticals (SMIPs), and shark variable IgNAR domains, are also encompassed within the expression "antigen-binding fragment," as used herein.

[0102] An antigen-binding fragment of an antibody will typically comprise at least one variable domain. The variable domain may be of any size or amino acid composition and will generally comprise at least one CDR, which is adjacent to or in frame with one

or more framework sequences. In antigen-binding fragments having a V_H domain associated with a V_L domain, the V_H and V_L domains may be situated relative to one another in any suitable arrangement. For example, the variable region may be dimeric and contain $V_H - V_H$, $V_H - V_L$ or $V_L - V_L$ dimers. Alternatively, the antigen-binding fragment of an antibody may contain a monomeric V_H or V_L domain.

[0103] In certain embodiments, an antigen-binding fragment of an antibody may contain at least one variable domain covalently linked to at least one constant domain. Non-limiting, exemplary configurations of variable and constant domains that may be found within an antigen-binding fragment of an antibody of the present invention include: (i) $V_H - C_H1$; (ii) $V_H - C_H2$; (iii) $V_H - C_H3$; (iv) $V_H - C_H1 - C_H2$; (v) $V_H - C_H1 - C_H2 - C_H3$; (vi) $V_H - C_H2 - C_H3$; (vii) $V_H - C_L$; (viii) $V_L - C_H1$; (ix) $V_L - C_H2$; (x) $V_L - C_H3$; (xi) $V_L - C_H1 - C_H2$; (xii) $V_L - C_H1 - C_H2 - C_H3$; (xiii) $V_L - C_H2 - C_H3$; and (xiv) $V_L - C_L$. In any configuration of variable and constant domains, including any of the exemplary configurations listed above, the variable and constant domains may be either directly linked to one another or may be linked by a full or partial hinge or linker region. A hinge region may consist of at least 2 (*e.g.*, 5, 10, 15, 20, 40, 60 or more) amino acids, which result in a flexible or semi-flexible linkage between adjacent variable and/or constant domains in a single polypeptide molecule. Moreover, an antigen-binding fragment of an antibody of the present invention may comprise a homo-dimer or hetero-dimer (or other multimer) of any of the variable and constant domain configurations listed above in non-covalent association with one another and/or with one or more monomeric V_H or V_L domain (*e.g.*, by disulfide bond(s)).

[0104] As with full antibody molecules, antigen-binding fragments may be mono-specific or multi-specific (*e.g.*, bi-specific). A multi-specific antigen-binding fragment of an antibody will typically comprise at least two different variable domains, wherein each variable domain is capable of specifically binding to a separate antigen or to a different epitope on the same antigen. Any multi-specific antibody format, including the exemplary bi-specific antibody formats disclosed herein, may be adapted for use in the context of an antigen-binding fragment of an antibody of the present invention using routine techniques available in the art.

Preparation of Human Antibodies

[0105] Methods for generating human antibodies in transgenic mice are known in the art. Any such known methods can be used in the context of the present invention to make human antibodies that specifically bind to C5 protein.

[0106] An immunogen comprising any one of the following can be used to generate antibodies to C5 protein. In certain embodiments, the antibodies of the invention are obtained from mice immunized with a full length, native C5 protein (See, for example, GenBank accession number NP_001726.2) (SEQ ID NO: 355), or with DNA encoding the protein or fragment thereof. Alternatively, the protein or a fragment thereof may be produced using standard biochemical techniques and modified and used as immunogen. In certain embodiments of the invention, the immunogen is a fragment of C5 protein that ranges from about amino acid residues 19 – 1676 of SEQ ID NO: 355.

[0107] In some embodiments, the immunogen may be a recombinant C5 protein or fragment thereof expressed in *E. coli* or in any other eukaryotic or mammalian cells such as Chinese hamster ovary (CHO) cells.

[0108] Using VELOCIMMUNE® technology (see, for example, US 6,596,541, Regeneron Pharmaceuticals, VELOCIMMUNE®) or any other known method for generating monoclonal antibodies, high affinity chimeric antibodies to C5 are initially isolated having a human variable region and a mouse constant region. The VELOCIMMUNE® technology involves generation of a transgenic mouse having a genome comprising human heavy and light chain variable regions operably linked to endogenous mouse constant region loci such that the mouse produces an antibody comprising a human variable region and a mouse constant region in response to antigenic stimulation. The DNA encoding the variable regions of the heavy and light chains of the antibody are isolated and operably linked to DNA encoding the human heavy and light chain constant regions. The DNA is then expressed in a cell capable of expressing the fully human antibody.

[0109] Generally, a VELOCIMMUNE® mouse is challenged with the antigen of interest, and lymphatic cells (such as B-cells) are recovered from the mice that express antibodies. The lymphatic cells may be fused with a myeloma cell line to prepare immortal hybridoma cell lines, and such hybridoma cell lines are screened and selected to identify hybridoma cell lines that produce antibodies specific to the antigen of interest. DNA encoding the variable regions of the heavy chain and light chain may be isolated and linked to desirable isotopic constant regions of the heavy chain and light

chain. Such an antibody protein may be produced in a cell, such as a CHO cell. Alternatively, DNA encoding the antigen-specific chimeric antibodies or the variable domains of the light and heavy chains may be isolated directly from antigen-specific lymphocytes.

[0110] Initially, high affinity chimeric antibodies are isolated having a human variable region and a mouse constant region. As in the experimental section below, the antibodies are characterized and selected for desirable characteristics, including affinity, selectivity, epitope, etc. The mouse constant regions are replaced with a desired human constant region to generate the fully human antibody of the invention, for example wild-type or modified IgG1 or IgG4. While the constant region selected may vary according to specific use, high affinity antigen-binding and target specificity characteristics reside in the variable region.

Bioequivalents

[0111] The anti-C5 antibodies and antibody fragments of the present invention encompass proteins having amino acid sequences that vary from those of the described antibodies, but that retain the ability to bind C5 protein. Such variant antibodies and antibody fragments comprise one or more additions, deletions, or substitutions of amino acids when compared to parent sequence, but exhibit biological activity that is essentially equivalent to that of the described antibodies. Likewise, the antibody-encoding DNA sequences of the present invention encompass sequences that comprise one or more additions, deletions, or substitutions of nucleotides when compared to the disclosed sequence, but that encode an antibody or antibody fragment that is essentially bioequivalent to an antibody or antibody fragment of the invention.

[0112] Two antigen-binding proteins, or antibodies, are considered bioequivalent if, for example, they are pharmaceutical equivalents or pharmaceutical alternatives whose rate and extent of absorption do not show a significant difference when administered at the same molar dose under similar experimental conditions, either single dose or multiple doses. Some antibodies will be considered equivalents or pharmaceutical alternatives if they are equivalent in the extent of their absorption but not in their rate of absorption and yet may be considered bioequivalent because such differences in the rate of absorption are intentional and are reflected in the labeling, are not essential to the attainment of effective body drug concentrations on, *e.g.*, chronic use, and are considered medically insignificant for the particular drug product studied.

[0113] In one embodiment, two antigen-binding proteins are bioequivalent if there are no clinically meaningful differences in their safety, purity, or potency.

[0114] In one embodiment, two antigen-binding proteins are bioequivalent if a patient can be switched one or more times between the reference product and the biological product without an expected increase in the risk of adverse effects, including a clinically significant change in immunogenicity, or diminished effectiveness, as compared to continued therapy without such switching.

[0115] In one embodiment, two antigen-binding proteins are bioequivalent if they both act by a common mechanism or mechanisms of action for the condition or conditions of use, to the extent that such mechanisms are known.

[0116] Bioequivalence may be demonstrated by *in vivo* and/or *in vitro* methods. Bioequivalence measures include, *e.g.*, (a) an *in vivo* test in humans or other mammals, in which the concentration of the antibody or its metabolites is measured in blood, plasma, serum, or other biological fluid as a function of time; (b) an *in vitro* test that has been correlated with and is reasonably predictive of human *in vivo* bioavailability data; (c) an *in vivo* test in humans or other mammals in which the appropriate acute pharmacological effect of the antibody (or its target) is measured as a function of time; and (d) in a well-controlled clinical trial that establishes safety, efficacy, or bioavailability or bioequivalence of an antibody.

[0117] Bioequivalent variants of the antibodies of the invention may be constructed by, for example, making various substitutions of residues or sequences or deleting terminal or internal residues or sequences not needed for biological activity. For example, cysteine residues not essential for biological activity can be deleted or replaced with other amino acids to prevent formation of unnecessary or incorrect intramolecular disulfide bridges upon renaturation. In other contexts, bioequivalent antibodies may include antibody variants comprising amino acid changes, which modify the glycosylation characteristics of the antibodies, *e.g.*, mutations that eliminate or remove glycosylation.

Anti-C5 Antibodies Comprising Fc Variants

[0118] According to certain embodiments of the present invention, anti-C5 antibodies are provided comprising an Fc domain comprising one or more mutations which enhance or diminish antibody binding to the FcRn receptor, *e.g.*, at acidic pH as compared to neutral pH. For example, the present invention includes anti-C5

antibodies comprising a mutation in the C_H2 or a C_H3 region of the Fc domain, wherein the mutation(s) increases the affinity of the Fc domain to FcRn in an acidic environment (*e.g.*, in an endosome where pH ranges from about 5.5 to about 6.0). Such mutations may result in an increase in serum half-life of the antibody when administered to an animal. Non-limiting examples of such Fc modifications include, *e.g.*, a modification at position 250 (*e.g.*, E or Q); 250 and 428 (*e.g.*, L or F); 252 (*e.g.*, L/Y/F/W or T), 254 (*e.g.*, S or T), and 256 (*e.g.*, S/R/Q/E/D or T); or a modification at position 428 and/or 433 (*e.g.*, H/L/R/S/P/Q or K) and/or 434 (*e.g.*, A, W, H, F or Y [N434A, N434W, N434H, N434F or N434Y]); or a modification at position 250 and/or 428; or a modification at position 307 or 308 (*e.g.*, 308F, V308F), and 434. In one embodiment, the modification comprises a 428L (*e.g.*, M428L) and 434S (*e.g.*, N434S) modification; a 428L, 259I (*e.g.*, V259I), and 308F (*e.g.*, V308F) modification; a 433K (*e.g.*, H433K) and a 434 (*e.g.*, 434Y) modification; a 252, 254, and 256 (*e.g.*, 252Y, 254T, and 256E) modification; a 250Q and 428L modification (*e.g.*, T250Q and M428L); and a 307 and/or 308 modification (*e.g.*, 308F or 308P). In yet another embodiment, the modification comprises a 265A (*e.g.*, D265A) and/or a 297A (*e.g.*, N297A) modification.

[0119] For example, the present invention includes anti-C5 antibodies comprising an Fc domain comprising one or more pairs or groups of mutations selected from the group consisting of: 250Q and 248L (*e.g.*, T250Q and M248L); 252Y, 254T and 256E (*e.g.*, M252Y, S254T and T256E); 428L and 434S (*e.g.*, M428L and N434S); 257I and 311I (*e.g.*, P257I and Q311I); 257I and 434H (*e.g.*, P257I and N434H); 376V and 434H (*e.g.*, D376V and N434H); 307A, 380A and 434A (*e.g.*, T307A, E380A and N434A); and 433K and 434F (*e.g.*, H433K and N434F). All possible combinations of the foregoing Fc domain mutations and other mutations within the antibody variable domains disclosed herein, are contemplated within the scope of the present invention.

[0120] The present invention also includes anti-C5 antibodies comprising a chimeric heavy chain constant (C_H) region, wherein the chimeric C_H region comprises segments derived from the C_H regions of more than one immunoglobulin isotype. For example, the antibodies of the invention may comprise a chimeric C_H region comprising part or all of a C_H2 domain derived from a human IgG1, human IgG2 or human IgG4 molecule, combined with part or all of a C_H3 domain derived from a human IgG1, human IgG2 or human IgG4 molecule. According to certain embodiments, the antibodies of the invention comprise a chimeric C_H region having a chimeric hinge

region. For example, a chimeric hinge may comprise an "upper hinge" amino acid sequence (amino acid residues from positions 216 to 227 according to EU numbering) derived from a human IgG1, a human IgG2 or a human IgG4 hinge region, combined with a "lower hinge" sequence (amino acid residues from positions 228 to 236 according to EU numbering) derived from a human IgG1, a human IgG2 or a human IgG4 hinge region. According to certain embodiments, the chimeric hinge region comprises amino acid residues derived from a human IgG1 or a human IgG4 upper hinge and amino acid residues derived from a human IgG2 lower hinge. An antibody comprising a chimeric C_H region as described herein may, in certain embodiments, exhibit modified Fc effector functions without adversely affecting the therapeutic or pharmacokinetic properties of the antibody. (*See, e.g.*, U.S. Patent Application Publication 2014/0243504, the disclosure of which is hereby incorporated by reference in its entirety).

Biological Characteristics of the Antibodies

[0121] In general, the antibodies of the present invention function by binding to C5 protein and preventing its cleavage to C5a and C5b. For example, the present invention includes antibodies and antigen-binding fragments of antibodies that bind C5 protein (*e.g.*, at 25°C or at 37°C) with a K_D of less than 9nM as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof bind C5 with a K_D of less than about 9nM, less than about 5nM, less than about 2nM, less than about 1nM, less than about 500pM, less than 250pM, or less than 100pM, as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein, or a substantially similar assay.

[0122] The present invention also includes antibodies and antigen-binding fragments thereof that bind human C5 protein with a dissociative half-life (t_{1/2}) of greater than about 2 minutes as measured by surface plasmon resonance at 25°C, *e.g.*, using an assay format as defined in Example 4 herein, or a substantially similar assay. In certain embodiments, the antibodies or antigen-binding fragments of the present invention bind C5 protein with a t_{1/2} of greater than about 5 minutes, greater than about 10 minutes, greater than about 30 minutes, greater than about 50 minutes, greater than about 100 minutes, greater than about 150 minutes, greater than about 200 minutes, or greater than about 250 minutes, as measured by surface plasmon resonance at 25°C, *e.g.*, using

an assay format as defined in Example 3 herein (*e.g.*, mAb-capture or antigen-capture format), or a substantially similar assay.

[0123] The present invention also includes antibodies and antigen-binding fragments thereof that bind human C5 protein with a dissociative half-life ($t_{1/2}$) of greater than about 1.5 minutes as measured by surface plasmon resonance at 37°C, *e.g.*, using an assay format as defined in Example 4 herein, or a substantially similar assay. In certain embodiments, the antibodies or antigen-binding fragments of the present invention bind C5 protein with a $t_{1/2}$ of greater than about 2 minutes, greater than about 5 minutes, greater than about 10 minutes, greater than about 25 minutes, greater than about 50 minutes, greater than about 100 minutes, greater than about 150 minutes, or greater than about 200 minutes, as measured by surface plasmon resonance at 37°C, *e.g.*, using an assay format as defined in Example 3 herein (*e.g.*, mAb-capture or antigen-capture format), or a substantially similar assay.

[0124] The present invention also includes antibodies and antigen-binding fragments of antibodies that bind monkey C5 protein (*e.g.*, at 25°C or at 37°C) with a K_D of less than 120nM as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof bind monkey C5 with a K_D of less than about 120nM, less than about 100nM, less than about 50nM, less than about 25nM, less than about 10nM, less than about 5nM, less than about 1nM, less than about 500pM, or less than 250pM, as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein, or a substantially similar assay.

[0125] The present invention also includes antibodies and antigen-binding fragments of antibodies that bind modified human C5 protein with R885H change (exemplified by SEQ ID NO: 356) with a K_D of less than 70nM as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein. C5 variants have shown poor response to anti-C5 antibodies previously disclosed in the art (*e.g.*, Nishimura *et al* 2014, New Engl. J. Med. 370: 632-639). In certain embodiments, the antibodies or antigen-binding fragments thereof bind the modified human C5 with a K_D of less than about 65nM, less than about 50nM, less than about 20nM, less than about 10nM, less than about 5nM, less than about 3nM, or less than 2nM, as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein, or a substantially similar assay.

[0126] The present invention also includes antibodies and antigen-binding fragments of antibodies that bind modified human C5 protein with R885C change (exemplified by SEQ ID NO: 357) with a K_D of less than 160nM as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein. C5 variants have shown poor response to anti-C5 antibodies previously disclosed in the art (*e.g.*, Nishimura *et al* 2014, New Engl. J. Med. 370: 632-639). In certain embodiments, the antibodies or antigen-binding fragments thereof bind the modified human C5 with a K_D of less than about 150nM, less than about 100nM, less than about 50nM, less than about 20nM, less than about 10nM, less than about 5nM, or less than 2nM, as measured by surface plasmon resonance, *e.g.*, using the assay format as defined in Example 3 herein, or a substantially similar assay.

[0127] The present invention also includes antibodies and antigen-binding fragments of antibodies that inhibit complement dependent cytotoxicity (CDC) with IC_{50} less than 10nM as measured by a luminescence assay, *e.g.*, using the assay format as defined in Example 6 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof inhibit CDC with IC_{50} less than about 5nM, less than about 3.5nM, or less than about 2nM, as measured by a B-cell luminescence assay, *e.g.*, using the assay format as defined in Example 6 herein, or a substantially similar assay.

[0128] The present invention also includes antibodies and antigen-binding fragments that block human C5-mediated classical pathway (CP) hemolysis by more than 94% and with an IC_{50} less than 6nM, as measured by a CP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof block CP hemolysis with IC_{50} less than about 6nM, less than about 5nM, less than about 4nM, less than about 3nM, or less than about 2nM, as measured by CP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein, or a substantially similar assay.

[0129] The present invention also includes antibodies and antigen-binding fragments that block human C5-mediated alternative pathway (AP) hemolysis by more than 70% and with an IC_{50} less than 165nM, as measured by a AP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof block AP hemolysis with IC_{50} less than about 160nM, less than about 150nM, less than about 100nM, less than about 50nM, or less than about 20nM, as measured by AP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein, or a substantially similar assay.

[0130] The present invention also includes antibodies and antigen-binding fragments that block African green monkey C5-mediated classical pathway (CP) hemolysis by more than 40% and with an IC_{50} less than 185nM, as measured by a CP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof block CP hemolysis with IC_{50} less than about 180nM, less than about 150nM, less than about 100nM, less than about 75nM, or less than about 50nM, as measured by CP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein, or a substantially similar assay.

[0131] The present invention also includes antibodies and antigen-binding fragments that block African green monkey C5-mediated alternative pathway (AP) hemolysis with an IC_{50} less than 235nM, as measured by a AP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof block AP hemolysis with IC_{50} less than about 200nM, less than about 150nM, less than about 100nM, less than about 50nM, or less than about 20nM, as measured by AP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein, or a substantially similar assay.

[0132] The present invention also includes antibodies and antigen-binding fragments that block more than 90% of cynomolgus monkey C5-mediated classical pathway (CP) hemolysis with an IC_{50} less than 145nM, as measured by a CP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof block CP hemolysis with IC_{50} less than about 140nM, less than about 120nM, less than about 100nM, less than about 75nM, or less than about 50nM, as measured by CP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein, or a substantially similar assay.

[0133] The present invention also includes antibodies and antigen-binding fragments that block cynomolgus monkey C5-mediated alternative pathway (AP) hemolysis with an IC_{50} less than 30nM, as measured by an AP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein. In certain embodiments, the antibodies or antigen-binding fragments thereof block AP hemolysis with IC_{50} less than about 25nM, less than about 20nM, less than about 10nM, less than about 5nM, or less than about 2nM, as measured by AP hemolysis assay, *e.g.*, using the assay format as defined in Example 8 herein, or a substantially similar assay.

[0134] The present invention also includes antibodies and antigen-binding fragments that show improved pharmacokinetic (PK) and pharmacodynamic (PD) properties as

compared to anti-C5 antibodies in the art. The anti-C5 antibodies of the present invention show less susceptibility to target-mediated clearance upon administration, as shown in Examples 9 and 10 herein. In certain embodiments, the present invention includes anti-C5 antibodies and antigen-binding fragments thereof that show serum concentrations for extended periods, *e.g.*, more than 20 days, more than 25 days, more than 30 days, more than 35 days, more than 40 days, more than 45 days, more than 50 days, more than 55 days, or more than 60 days, as described in Examples 9 and 10 herein. In certain embodiments, the anti-C5 antibodies of the present invention show an extended serum half-life of more than 10 days, as compared to anti-C5 antibodies in the art.

[0135] In certain embodiments, the present invention provides anti-C5 antibodies and antigen-binding fragments thereof that have high affinity for human C5 (*e.g.*, K_D less than 0.3nM) and a lower clearance (*e.g.*, extended serum half-life, improved pharmacodynamic activity over more days than previously known anti-C5 antibodies). Such antibodies of the present invention may be advantageously used with less frequent dosing in a subject with a C5-associated disease or disorder.

[0136] In one embodiment, the present invention provides an isolated recombinant antibody or antigen-binding fragment thereof that binds specifically to C5 protein, wherein the antibody or fragment thereof exhibits one or more of the following characteristics: (a) is a fully human monoclonal antibody; (b) binds to human C5 with a dissociation constant (K_D) of less than 0.9nM at 25°C, as measured in a surface plasmon resonance assay; (c) binds to human C5 with a K_D of less than 0.3nM at 37°C, as measured in a surface plasmon resonance assay; (d) has serum concentration of more than 10 µg/mL through day 70 upon administration to cynomolgus monkey; (e) blocks CP- and AP hemolysis through day 35 upon administration to cynomolgus monkey, as measured in an *ex vivo* hemolysis assay; (f) has serum half-life of more than 10 days in cynomolgus monkey; (g) has serum concentration of more than 10 µg/mL through day 40 upon administration to C5-humanized mice; (h) blocks CP hemolysis through day 30 upon administration to C5-humanized mice, as measured in an *ex vivo* hemolysis assay; and (i) has serum half-life of more than 10 days in C5-humanized mice.

[0137] In one embodiment, the present invention provides an isolated recombinant antibody or antigen-binding fragment thereof that binds specifically to C5 protein, wherein the antibody or fragment thereof exhibits one or more of the following characteristics: (a) is a fully human monoclonal antibody; (b) binds to human C5 with a

dissociation constant (K_D) of less than 0.9nM at 25°C, as measured in a surface plasmon resonance assay; (c) binds to human C5 with a K_D of less than 0.3nM at 37°C, as measured in a surface plasmon resonance assay; (d) binds to monkey C5 with a K_D of less than 65nM, as measured in a surface plasmon resonance assay; (e) binds to human C5 variant R885H (SEQ ID NO: 356) with a K_D of less than 0.5nM, as measured in a surface plasmon resonance assay; (f) binds to human C5 variant R885C (SEQ ID NO: 357) with a K_D of less than 0.5nM, as measured in a surface plasmon resonance assay; (g) blocks human C5-mediated classical pathway (CP) hemolysis by more than 95% and with IC_{50} less than 6nM, as measured in a CP hemolysis assay; (h) blocks human C5-mediated alternative pathway (AP) hemolysis by more than 70% and with IC_{50} less than 165nM, as measured in a AP hemolysis assay; (i) inhibits African green monkey C5-mediated CP hemolysis with IC_{50} less than 185nM, as measured in a CP hemolysis assay; (j) inhibits African green monkey C5-mediated AP hemolysis with IC_{50} less than 235nM, as measured in a AP hemolysis assay; (k) inhibits cynomolgus monkey C5-mediated CP hemolysis with IC_{50} less than 145nM, as measured in a CP hemolysis assay; and (l) inhibits cynomolgus monkey C5-mediated AP hemolysis with IC_{50} less than 30nM, as measured in a AP hemolysis assay.

[0138] The antibodies of the present invention may possess one or more of the aforementioned biological characteristics, or any combinations thereof. Other biological characteristics of the antibodies of the present invention will be evident to a person of ordinary skill in the art from a review of the present disclosure including the working Examples herein.

Epitope Mapping and Related Technologies

[0139] The present invention includes anti-C5 antibodies which interact with one or more amino acids found within one or more regions of the C5 protein molecule including, the alpha polypeptide and beta polypeptide. The epitope to which the antibodies bind may consist of a single contiguous sequence of 3 or more (*e.g.*, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 or more) amino acids located within any of the aforementioned domains of the C5 protein molecule (*e.g.* a linear epitope in a domain). Alternatively, the epitope may consist of a plurality of non-contiguous amino acids (or amino acid sequences) located within either or both of the aforementioned domains of the protein molecule (*e.g.* a conformational epitope).

[0140] Various techniques known to persons of ordinary skill in the art can be used to determine whether an antibody "interacts with one or more amino acids" within a polypeptide or protein. Exemplary techniques include, for example, routine cross-blocking assays, such as that described in *Antibodies*, Harlow and Lane (Cold Spring Harbor Press, Cold Spring Harbor, NY). Other methods include alanine scanning mutational analysis, peptide blot analysis (Reineke (2004) *Methods Mol. Biol.* 248: 443-63), peptide cleavage analysis crystallographic studies and NMR analysis. In addition, methods such as epitope excision, epitope extraction and chemical modification of antigens can be employed (Tomer (2000) *Prot. Sci.* 9: 487-496). Another method that can be used to identify the amino acids within a polypeptide with which an antibody interacts is hydrogen/deuterium exchange detected by mass spectrometry. In general terms, the hydrogen/deuterium exchange method involves deuterium-labeling the protein of interest, followed by binding the antibody to the deuterium-labeled protein. Next, the protein/antibody complex is transferred to water and exchangeable protons within amino acids that are protected by the antibody complex undergo deuterium-to-hydrogen back-exchange at a slower rate than exchangeable protons within amino acids that are not part of the interface. As a result, amino acids that form part of the protein/antibody interface may retain deuterium and therefore exhibit relatively higher mass compared to amino acids not included in the interface. After dissociation of the antibody, the target protein is subjected to protease cleavage and mass spectrometry analysis, thereby revealing the deuterium-labeled residues which correspond to the specific amino acids with which the antibody interacts. *See, e.g.*, Ehring (1999) *Analytical Biochemistry* 267: 252-259; Engen and Smith (2001) *Anal. Chem.* 73: 256A-265A.

[0141] The term "epitope" refers to a site on an antigen to which B and/or T cells respond. B-cell epitopes can be formed both from contiguous amino acids or noncontiguous amino acids juxtaposed by tertiary folding of a protein. Epitopes formed from contiguous amino acids are typically retained on exposure to denaturing solvents, whereas epitopes formed by tertiary folding are typically lost on treatment with denaturing solvents. An epitope typically includes at least 3, and more usually, at least 5 or 8-10 amino acids in a unique spatial conformation.

[0142] Modification-Assisted Profiling (MAP), also known as Antigen Structure-based Antibody Profiling (ASAP) is a method that categorizes large numbers of monoclonal antibodies (mAbs) directed against the same antigen according to the

similarities of the binding profile of each antibody to chemically or enzymatically modified antigen surfaces (see US 2004/0101920, herein specifically incorporated by reference in its entirety). Each category may reflect a unique epitope either distinctly different from or partially overlapping with epitope represented by another category. This technology allows rapid filtering of genetically identical antibodies, such that characterization can be focused on genetically distinct antibodies. When applied to hybridoma screening, MAP may facilitate identification of rare hybridoma clones that produce mAbs having the desired characteristics. MAP may be used to sort the antibodies of the invention into groups of antibodies binding different epitopes.

[0143] In certain embodiments, the anti-C5 antibodies or antigen-binding fragments thereof bind an epitope within any one or more of the regions exemplified in C5 protein, either in natural form, as exemplified in SEQ ID NO: 355, or recombinantly produced, or to a fragment thereof. In some embodiments, the antibodies of the invention bind to a region comprising one or more amino acids selected from the group consisting of amino acid residues 19 – 1676 of human C5 protein.

[0144] In certain embodiments, the antibodies of the invention, interact with at least one amino acid sequence selected from the group consisting of amino acid residues ranging from about position 19 to about position 750; or amino acid residues ranging from about position 751 to about position 1676 of SEQ ID NO: 355.

[0145] In certain embodiments, the present invention includes anti-C5 antibodies and antigen-binding fragments thereof that interact with one or more epitopes found within the alpha and/or the beta chain of C5 (SEQ ID NO: 359). The epitope(s) may consist of one or more contiguous sequences of 3 or more (*e.g.*, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 or more) amino acids located within alpha chain and/or beta chain of C5. Alternatively, the epitope may consist of a plurality of non-contiguous amino acids (or amino acid sequences) located within C5. As shown in Example 11 herein, the epitope of C5 with which the exemplary antibody of the invention H4H12166P interacts is defined by: (i) the amino acid sequence NMGTMDSW (SEQ ID NO: 360) which corresponds to amino acids 591 to 599 comprised in the beta chain of SEQ ID NO: 359; and (ii) the amino acid sequence WEVHLVPRRKQLQFALPDSL (SEQ ID NO: 361), which corresponds to amino acids 775 to 794 comprised in the alpha chain of SEQ ID NO: 359. Accordingly, the present invention includes anti-C5 antibodies that interact with one or more amino acids contained within the region consisting of (i) the amino acid sequence NMGTMDSW (SEQ ID NO: 360), which

corresponds to amino acids 591 to 599 of SEQ ID NO: 359; and (ii) the amino acid sequence WEVHLVPRRKQLQFALPDSL (SEQ ID NO: 361), which corresponds to amino acids 775 to 794 of SEQ ID NO: 359.

[0146] The present invention includes anti-C5 antibodies that bind to the same epitope, or a portion of the epitope, as any of the specific exemplary antibodies listed in Table 1. Likewise, the present invention also includes anti-C5 antibodies that compete for binding to C5 protein or a fragment thereof with any of the specific exemplary antibodies listed in Table 1. For example, the present invention includes anti-C5 antibodies that cross-compete for binding to C5 protein with one or more antibodies listed in Table 1.

[0147] One can easily determine whether an antibody binds to the same epitope as, or competes for binding with, a reference anti-C5 antibody by using routine methods known in the art. For example, to determine if a test antibody binds to the same epitope as a reference anti-C5 antibody of the invention, the reference antibody is allowed to bind to a C5 protein or peptide under saturating conditions. Next, the ability of a test antibody to bind to the C5 protein molecule is assessed. If the test antibody is able to bind to C5 following saturation binding with the reference anti-C5 antibody, it can be concluded that the test antibody binds to a different epitope than the reference anti-C5 antibody. On the other hand, if the test antibody is not able to bind to the C5 protein following saturation binding with the reference anti-C5 antibody, then the test antibody may bind to the same epitope as the epitope bound by the reference anti-C5 antibody of the invention.

[0148] To determine if an antibody competes for binding with a reference anti-C5 antibody, the above-described binding methodology is performed in two orientations: In a first orientation, the reference antibody is allowed to bind to a C5 protein under saturating conditions followed by assessment of binding of the test antibody to the C5 molecule. In a second orientation, the test antibody is allowed to bind to a C5 molecule under saturating conditions followed by assessment of binding of the reference antibody to the C5 molecule. If, in both orientations, only the first (saturating) antibody is capable of binding to the C5 molecule, then it is concluded that the test antibody and the reference antibody compete for binding to C5. As will be appreciated by a person of ordinary skill in the art, an antibody that competes for binding with a reference antibody may not necessarily bind to the identical epitope as the reference

antibody, but may sterically block binding of the reference antibody by binding an overlapping or adjacent epitope.

[0149] Two antibodies bind to the same or overlapping epitope if each competitively inhibits (blocks) binding of the other to the antigen. That is, a 1-, 5-, 10-, 20- or 100-fold excess of one antibody inhibits binding of the other by at least 50% but preferably 75%, 90% or even 99% as measured in a competitive binding assay (see, *e.g.*, Junghans *et al.*, Cancer Res. 1990 50:1495-1502). Alternatively, two antibodies have the same epitope if essentially 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.

[0150] Additional routine experimentation (*e.g.*, peptide mutation and binding analyses) can then be carried out to confirm whether the observed lack of binding of the test antibody is in fact due to binding to the same epitope as the reference antibody or if steric blocking (or another phenomenon) is responsible for the lack of observed binding. Experiments of this sort can be performed using ELISA, RIA, surface plasmon resonance, flow cytometry or any other quantitative or qualitative antibody-binding assay available in the art.

Immunoconjugates

[0151] The invention encompasses a human anti-C5 monoclonal antibody conjugated to a therapeutic moiety ("immunoconjugate"), to treat a C5-associated disease or disorder (*e.g.*, atypical hemolytic uremic syndrome). As used herein, the term "immunoconjugate" refers to an antibody which is chemically or biologically linked to a radioactive agent, a cytokine, an interferon, a target or reporter moiety, an enzyme, a peptide or protein or a therapeutic agent. The antibody may be linked to the radioactive agent, cytokine, interferon, target or reporter moiety, enzyme, peptide or therapeutic agent at any location along the molecule so long as it is able to bind its target. Examples of immunoconjugates include antibody drug conjugates and antibody-toxin fusion proteins. In one embodiment, the agent may be a second different antibody to C5 protein. The type of therapeutic moiety that may be conjugated to the anti-C5 antibody and will take into account the condition to be treated and the desired therapeutic effect to be achieved. Examples of suitable agents for forming immunoconjugates are known in the art; see for example, WO 05/103081.

Multi-specific Antibodies

[0152] The antibodies of the present invention may be mono-specific, bi-specific, or multi-specific. Multi-specific antibodies may be specific for different epitopes of one target polypeptide or may contain antigen-binding domains specific for more than one target polypeptide. See, *e.g.*, Tutt *et al.*, 1991, J. Immunol. 147:60-69; Kufer *et al.*, 2004, Trends Biotechnol. 22:238-244.

[0153] Any of the multi-specific antigen-binding molecules of the invention, or variants thereof, may be constructed using standard molecular biological techniques (*e.g.*, recombinant DNA and protein expression technology), as will be known to a person of ordinary skill in the art.

[0154] In some embodiments, C5-specific antibodies are generated in a bi-specific format (a "bi-specific") in which variable regions binding to distinct domains of C5 protein are linked together to confer dual-domain specificity within a single binding molecule. Appropriately designed bi-specifics may enhance overall C5-protein inhibitory efficacy through increasing both specificity and binding avidity. Variable regions with specificity for individual domains, (*e.g.*, segments of the N-terminal domain), or that can bind to different regions within one domain, are paired on a structural scaffold that allows each region to bind simultaneously to the separate epitopes, or to different regions within one domain. In one example for a bi-specific, heavy chain variable regions (V_H) from a binder with specificity for one domain are recombined with light chain variable regions (V_L) from a series of binders with specificity for a second domain to identify non-cognate V_L partners that can be paired with an original V_H without disrupting the original specificity for that V_H. In this way, a single V_L segment (*e.g.*, V_{L1}) can be combined with two different V_H domains (*e.g.*, V_{H1} and V_{H2}) to generate a bi-specific comprised of two binding "arms" (V_{H1}- V_{L1} and V_{H2}- V_{L1}). Use of a single V_L segment reduces the complexity of the system and thereby simplifies and increases efficiency in cloning, expression, and purification processes used to generate the bi-specific (See, for example, USSN13/022759 and US2010/0331527).

[0155] Alternatively, antibodies that bind more than one domains and a second target, such as, but not limited to, for example, a second different anti-C5 antibody, may be prepared in a bi-specific format using techniques described herein, or other techniques known to those skilled in the art. Antibody variable regions binding to distinct regions

may be linked together with variable regions that bind to relevant sites on, for example, the extracellular domain of C5, to confer dual-antigen specificity within a single binding molecule. Appropriately designed bi-specifics of this nature serve a dual function. Variable regions with specificity for the extracellular domain are combined with a variable region with specificity for outside the extracellular domain and are paired on a structural scaffold that allows each variable region to bind to the separate antigens.

[0156] An exemplary bi-specific antibody format that can be used in the context of the present invention involves the use of a first immunoglobulin (Ig) C_H3 domain and a second Ig C_H3 domain, wherein the first and second Ig C_H3 domains differ from one another by at least one amino acid, and wherein at least one amino acid difference reduces binding of the bi-specific antibody to Protein A as compared to a bi-specific antibody lacking the amino acid difference. In one embodiment, the first Ig C_H3 domain binds Protein A and the second Ig C_H3 domain contains a mutation that reduces or abolishes Protein A binding such as an H95R modification (by IMGT exon numbering; H435R by EU numbering). The second C_H3 may further comprise a Y96F modification (by IMGT; Y436F by EU). Further modifications that may be found within the second C_H3 include: D16E, L18M, N44S, K52N, V57M, and V82I (by IMGT; D356E, L358M, N384S, K392N, V397M, and V422I by EU) in the case of IgG1 antibodies; N44S, K52N, and V82I (IMGT; N384S, K392N, and V422I by EU) in the case of IgG2 antibodies; and Q15R, N44S, K52N, V57M, R69K, E79Q, and V82I (by IMGT; Q355R, N384S, K392N, V397M, R409K, E419Q, and V422I by EU) in the case of IgG4 antibodies. Variations on the bi-specific antibody format described above are contemplated within the scope of the present invention.

[0157] Other exemplary bispecific formats that can be used in the context of the present invention include, without limitation, *e.g.*, scFv-based or diabody bispecific formats, IgG-scFv fusions, dual variable domain (DVD)-Ig, Quadroma, knobs-into-holes, common light chain (*e.g.*, common light chain with knobs-into-holes, etc.), CrossMab, CrossFab, (SEED)body, leucine zipper, Duobody, IgG1/IgG2, dual acting Fab (DAF)-IgG, and Mab² bispecific formats (*see, e.g.*, Klein *et al.* 2012, mAbs 4:6, 1-11, and references cited therein, for a review of the foregoing formats). Bispecific antibodies can also be constructed using peptide/nucleic acid conjugation, *e.g.*, wherein unnatural amino acids with orthogonal chemical reactivity are used to generate site-specific antibody-oligonucleotide conjugates which then self-assemble into multimeric

complexes with defined composition, valency and geometry. (See, e.g., Kazane *et al.*, *J. Am. Chem. Soc.* [Epub: Dec. 4, 2012]).

Therapeutic Administration and Formulations

[0158] The invention provides therapeutic compositions comprising the anti-C5 antibodies or antigen-binding fragments thereof of the present invention. Therapeutic compositions in accordance with the invention will be administered with suitable carriers, excipients, and other agents that are incorporated into formulations to provide improved transfer, delivery, tolerance, and the like. A multitude of appropriate formulations can be found in the formulary known to all pharmaceutical chemists: Remington's Pharmaceutical Sciences, Mack Publishing Company, Easton, PA. These formulations include, for example, powders, pastes, ointments, jellies, waxes, oils, lipids, lipid (cationic or anionic) containing vesicles (such as LIPOFECTIN™), DNA conjugates, anhydrous absorption pastes, oil-in-water and water-in-oil emulsions, emulsions carbowax (polyethylene glycols of various molecular weights), semi-solid gels, and semi-solid mixtures containing carbowax. See also Powell *et al.* "Compendium of excipients for parenteral formulations" PDA (1998) J Pharm Sci Technol 52:238-311.

[0159] The dose of antibody may vary depending upon the age and the size of a subject to be administered, target disease, conditions, route of administration, and the like. When an antibody of the present invention is used for treating a disease or disorder in an adult patient, or for preventing such a disease, it is advantageous to administer the antibody of the present invention normally at a single dose of about 0.1 to about 100 mg/kg body weight, more preferably about 5 to about 80, about 10 to about 70, or about 20 to about 50 mg/kg body weight. Depending on the severity of the condition, the frequency and the duration of the treatment can be adjusted. In certain embodiments, the antibody or antigen-binding fragment thereof of the invention can be administered as an initial dose of at least about 0.1 mg to about 800 mg, about 1 to about 600 mg, about 5 to about 500 mg, or about 10 to about 400 mg. In certain embodiments, the initial dose may be followed by administration of a second or a plurality of subsequent doses of the antibody or antigen-binding fragment thereof in an amount that can be approximately the same or less than that of the initial dose, wherein the subsequent doses are separated by at least 1 day to 3 days; at least one week, at least 2 weeks; at least 3 weeks; at least 4 weeks; at least 5 weeks; at least 6 weeks; at least 7 weeks; at

least 8 weeks; at least 9 weeks; at least 10 weeks; at least 12 weeks; or at least 14 weeks.

[0160] Various delivery systems are known and can be used to administer the pharmaceutical composition of the invention, *e.g.*, encapsulation in liposomes, microparticles, microcapsules, recombinant cells capable of expressing the mutant viruses, receptor mediated endocytosis (see, *e.g.*, Wu *et al.* (1987) J. Biol. Chem. 262:4429-4432). Methods of introduction include, but are not limited to, intradermal, transdermal, intramuscular, intraperitoneal, intravenous, subcutaneous, intranasal, epidural and oral routes. The composition may be administered by any convenient route, for example by infusion or bolus injection, by absorption through epithelial or mucocutaneous linings (*e.g.*, oral mucosa, rectal and intestinal mucosa, etc.) and may be administered together with other biologically active agents. Administration can be systemic or local. The pharmaceutical composition can be also delivered in a vesicle, in particular a liposome (see, for example, Langer (1990) Science 249:1527-1533).

[0161] The use of nanoparticles to deliver the antibodies of the present invention is also contemplated herein. Antibody-conjugated nanoparticles may be used both for therapeutic and diagnostic applications. Antibody-conjugated nanoparticles and methods of preparation and use are described in detail by Arruebo, M., *et al.* 2009 (“Antibody-conjugated nanoparticles for biomedical applications” in J. Nanomat. Volume 2009, Article ID 439389, 24 pages, doi: 10.1155/2009/439389), incorporated herein by reference. Nanoparticles may be developed and conjugated to antibodies contained in pharmaceutical compositions to target cells. Nanoparticles for drug delivery have also been described in, for example, US 8257740, or US 8246995, each incorporated herein in its entirety.

[0162] In certain situations, the pharmaceutical composition can be delivered in a controlled release system. In one embodiment, a pump may be used. In another embodiment, polymeric materials can be used. In yet another embodiment, a controlled release system can be placed in proximity of the composition’s target, thus requiring only a fraction of the systemic dose.

[0163] The injectable preparations may include dosage forms for intravenous, subcutaneous, intracutaneous, intracranial, intraperitoneal and intramuscular injections, drip infusions, etc. These injectable preparations may be prepared by methods publicly known. For example, the injectable preparations may be prepared, *e.g.*, by dissolving, suspending or emulsifying the antibody or its salt described above in a sterile aqueous

medium or an oily medium conventionally used for injections. As the aqueous medium for injections, there are, for example, physiological saline, an isotonic solution containing glucose and other auxiliary agents, etc., which may be used in combination with an appropriate solubilizing agent such as an alcohol (*e.g.*, ethanol), a polyalcohol (*e.g.*, propylene glycol, polyethylene glycol), a nonionic surfactant [*e.g.*, polysorbate 80, HCO-50 (polyoxyethylene (50 mol) adduct of hydrogenated castor oil)], etc. As the oily medium, there are employed, *e.g.*, sesame oil, soybean oil, etc., which may be used in combination with a solubilizing agent such as benzyl benzoate, benzyl alcohol, etc. The injection thus prepared is preferably filled in an appropriate ampoule.

[0164] A pharmaceutical composition of the present invention can be delivered subcutaneously or intravenously with a standard needle and syringe. In addition, with respect to subcutaneous delivery, a pen delivery device readily has applications in delivering a pharmaceutical composition of the present invention. Such a pen delivery device can be reusable or disposable. A reusable pen delivery device generally utilizes a replaceable cartridge that contains a pharmaceutical composition. Once all of the pharmaceutical composition within the cartridge has been administered and the cartridge is empty, the empty cartridge can readily be discarded and replaced with a new cartridge that contains the pharmaceutical composition. The pen delivery device can then be reused. In a disposable pen delivery device, there is no replaceable cartridge. Rather, the disposable pen delivery device comes prefilled with the pharmaceutical composition held in a reservoir within the device. Once the reservoir is emptied of the pharmaceutical composition, the entire device is discarded.

[0165] Numerous reusable pen and autoinjector delivery devices have applications in the subcutaneous delivery of a pharmaceutical composition of the present invention. Examples include, but certainly are not limited to AUTOPEN™ (Owen Mumford, Inc., Woodstock, UK), DISETRONIC™ pen (Disetronic Medical Systems, Burghdorf, Switzerland), HUMALOG MIX 75/25™ pen, HUMALOG™ pen, HUMALIN 70/30™ pen (Eli Lilly and Co., Indianapolis, IN), NOVOPEN™ I, II and III (Novo Nordisk, Copenhagen, Denmark), NOVOPEN JUNIOR™ (Novo Nordisk, Copenhagen, Denmark), BD™ pen (Becton Dickinson, Franklin Lakes, NJ), OPTIPEN™, OPTIPEN PRO™, OPTIPEN STARLET™, and OPTICLIK™ (Sanofi-Aventis, Frankfurt, Germany), to name only a few. Examples of disposable pen delivery devices having applications in subcutaneous delivery of a pharmaceutical composition of the present invention include, but certainly are not limited to the SOLOSTAR™ pen (Sanofi-

Aventis), the FLEXPEN™ (Novo Nordisk), and the KWIKPEN™ (Eli Lilly), the SURECLICK™ Autoinjector (Amgen, Thousand Oaks, CA), the PENLET™ (Haselmeier, Stuttgart, Germany), the EPIPEN (Dey, L.P.) and the HUMIRA™ Pen (Abbott Labs, Abbott Park, IL), to name only a few.

[0166] Advantageously, the pharmaceutical compositions for oral or parenteral use described above are prepared into dosage forms in a unit dose suited to fit a dose of the active ingredients. Such dosage forms in a unit dose include, for example, tablets, pills, capsules, injections (ampoules), suppositories, etc. The amount of the antibody contained is generally about 5 to about 500 mg per dosage form in a unit dose; especially in the form of injection, it is preferred that the antibody is contained in about 5 to about 300 mg and in about 10 to about 300 mg for the other dosage forms.

Therapeutic Uses of the Antibodies

[0167] The antibodies of the present invention are useful for the treatment, and/or prevention of a disease or disorder or condition associated with C5 and/or for ameliorating at least one symptom associated with such disease, disorder or condition. In certain embodiments, an antibody or antigen-binding fragment thereof of the invention may be administered at a therapeutic dose to a patient with a disease or disorder or condition associated with C5.

[0168] In certain embodiments, the antibodies of the present invention are useful in treating or preventing a symptom or indication of atypical hemolytic uremic syndrome (aHUS). Symptoms and indications of aHUS include, but are not limited to, platelet activation, hemolysis, systemic thrombotic microangiopathy (formation of blood clots in small blood vessels throughout the body) leading to stroke, heart attack, kidney failure and/or death, end-stage renal disease, permanent renal damage, abdominal pain, confusion, edema, fatigue, nausea/vomiting, diarrhea, and microangiopathic anemia.

[0169] In certain embodiments, the antibodies of the present invention are useful in treating or preventing a symptom or indication of paroxysmal nocturnal hemoglobinuria (PNH). Symptoms and indications of PNH include, but are not limited to, destruction of red blood cells, thrombosis (including deep vein thrombosis, pulmonary embolism), intravascular hemolytic anemia, red discoloration of urine, symptoms of anemia such as tiredness, shortness of breath, and palpitations, abdominal pain and difficulty swallowing.

[0170] In certain embodiments, the antibodies of the present invention are useful for treating or preventing at least one symptom or indication of a C5-associated disease or disorder selected from the group consisting of neurological disorders, renal disorders, multiple sclerosis, stroke, Guillain Barre Syndrome, traumatic brain injury, Parkinson's disease, disorders of inappropriate or undesirable complement activation, hemodialysis complications, hyperacute allograft rejection, xenograft rejection, interleukin-2 induced toxicity during IL-2 therapy, inflammatory disorders, inflammation of autoimmune diseases, Crohn's disease, adult respiratory distress syndrome, thermal injury including burns or frostbite, post-ischemic reperfusion conditions, myocardial infarction, capillary leak syndrome, obesity, diabetes, Alzheimer's disease, schizophrenia, stroke, epilepsy, atherosclerosis, vasculitis, bullous pemphigoid, C3 glomerulopathy, membranoproliferative glomerulonephritis, balloon angioplasty, post-pump syndrome in cardiopulmonary bypass or renal bypass, hemodialysis, renal ischemia, mesenteric artery reperfusion after aortic reconstruction, infectious disease or sepsis, immune complex disorders and autoimmune diseases, diabetic nephropathy, Alport's syndrome, progressive kidney failure, proteinuric kidney diseases, renal ischemia-reperfusion injury, lupus nephritis, glomerulopathy, rheumatoid arthritis, systemic lupus erythematosus (SLE), SLE nephritis, membrano-proliferative nephritis, hemolytic anemia, neuromyelitis optica, renal transplant, inherited CD59 deficiency, psoriasis, and myasthenia gravis. In certain other embodiments, the antibodies of the present invention are useful for treating or preventing at least one symptom or indication of a C5-associated disease or disorder selected from the group consisting of lung disease and disorders such as dyspnea, hemoptysis, ARDS, asthma, chronic obstructive pulmonary disease (COPD), emphysema, pulmonary embolisms and infarcts, pneumonia, fibrogenic dust diseases, injury due to inert dusts and minerals (*e.g.*, silicon, coal dust, beryllium, and asbestos), pulmonary fibrosis, organic dust diseases, chemical injury (due to irritant gasses and chemicals, *e.g.*, chlorine, phosgene, sulfur dioxide, hydrogen sulfide, nitrogen dioxide, ammonia, and hydrochloric acid), smoke injury, thermal injury (*e.g.*, burn, freeze), asthma, allergy, bronchoconstriction, hypersensitivity pneumonitis, parasitic diseases, Goodpasture's Syndrome, pulmonary vasculitis, hereditary angioedema, and immune complex-associated inflammation.

[0171] In certain embodiments, the antibodies of the invention are useful to treat subjects suffering from an ocular disease such as age-related macular degeneration (AMD), diabetic macular edema (DME), diabetic retinopathy, ocular angiogenesis

(ocular neovascularization affecting choroidal, corneal or retinal tissue), geographic atrophy (GA), uveitis and neuromyelitis optica. The antibodies of the present invention may be used to treat or to ameliorate at least one symptom or indication of dry AMD or wet AMD. In some embodiments, the antibodies of the invention are useful in preventing or slowing rate of loss of vision. In one embodiment, the antibodies of the present invention are useful in reducing drusen in the eye of a subject with dry AMD. In one embodiment, the antibodies of the present invention are useful in preventing or reducing/slowing loss of vision in a subject with AMD.

[0172] One or more antibodies of the present invention may be administered to relieve or prevent or decrease the severity of one or more of the symptoms or conditions/indications of the ocular disease or disorder. The antibodies may be used to ameliorate or reduce the severity of at least one symptom including, but not limited to loss of vision, visual distortion, difficulty adapting to low light levels, crooked central vision, increase in haziness of central/overall vision, presence of drusen (tiny accumulations of extracellular material that build up on the retina), pigmentary changes, distorted vision in the form of metamorphopsia, in which a grid of straight lines appears wavy and parts of the grid may appear blank, exudative changes (hemorrhages in the eye, hard exudates, subretinal/sub-RPE/intraretinal fluid), slow recovery of visual function after exposure to bright light (photostress test), incipient and geographic atrophy, visual acuity drastically decreasing (two levels or more), *e.g.*, 20/20 to 20/80, preferential hyperacuity perimetry changes (for wet AMD), blurred vision, gradual loss of central vision (for those with non-exudative macular degeneration, rapid onset of vision loss (often caused by leakage and bleeding of abnormal blood vessels in subjects with exudative macular degeneration, central scotomas (shadows or missing areas of vision), trouble discerning colors, specifically dark ones from dark ones and light ones from light ones, loss in contrast sensitivity, straight lines appear curved in an Amsler grid.

[0173] It is also contemplated herein to use one or more antibodies of the present invention prophylactically to subjects at risk for developing macular degeneration such as subjects over the age of 50, subjects with a family history of macular degeneration, smokers, and subjects with obesity, high cholesterol, cardiovascular disease, or unhealthy diet.

[0174] In a further embodiment of the invention the present antibodies are used for the preparation of a pharmaceutical composition or medicament for treating patients

suffering from a disease or disorder associated with C5. In another embodiment of the invention, the present antibodies are used as adjunct therapy with any other agent or any other therapy known to those skilled in the art useful for treating or ameliorating a disease or disorder associated with C5.

Combination Therapies

[0175] Combination therapies may include an anti-C5 antibody of the invention and any additional therapeutic agent that may be advantageously combined with an antibody of the invention, or with a biologically active fragment of an antibody of the invention. The antibodies of the present invention may be combined synergistically with one or more drugs or therapy used to treat a disease or disorder associated with C5. In some embodiments, the antibodies of the invention may be combined with a second therapeutic agent to ameliorate one or more symptoms of said disease.

[0176] Depending upon the C5-associated disease or disorder, the antibodies of the present invention may be used in combination with one or more additional therapeutic agents including, but not limited to, an anti-coagulant (*e.g.*, warfarin, aspirin, heparin, phenindione, fondaparinux, idraparinux, and thrombin inhibitors such as argatroban, lepirudin, bivalirudin, or dabigatran) an anti-inflammatory drug (*e.g.*, corticosteroids, and non-steroidal anti-inflammatory drugs), an antihypertensive (*e.g.*, an angiotensin-converting enzyme inhibitor), an immunosuppressive agent (*e.g.*, vincristine, cyclosporine A, or methotrexate), a fibrinolytic agent (*e.g.*, ancrod, ϵ -aminocaproic acid, antiplasmin-a₁, prostacyclin, and defibrotide), a lipid-lowering agent such as an inhibitor of hydroxymethylglutaryl CoA reductase, an anti-CD20 agent such as rituximab, an anti-TNF agent such as infliximab, an anti-seizure agent (*e.g.*, magnesium sulfate), a C3 inhibitor, or an anti-thrombotic agent.

[0177] In certain embodiments, the second therapeutic agent is another antibody to C5 protein. It is contemplated herein to use a combination (“cocktail”) of antibodies with broad neutralization or inhibitory activity against C5. In some embodiments, non-competing antibodies may be combined and administered to a subject in need thereof. In some embodiments, the antibodies comprising the combination bind to distinct non-overlapping epitopes on the protein. The antibodies comprising the combination may block the C5 binding to C5 convertase and/or may prevent/inhibit cleavage of C5 into C5a and C5b. In certain embodiments, the second antibody may possess longer half-life in human serum.

[0178] As used herein, the term “in combination with” means that additional therapeutically active component(s) may be administered prior to, concurrent with, or after the administration of the anti-C5 antibody of the present invention. The term “in combination with” also includes sequential or concomitant administration of an anti-C5 antibody and a second therapeutic agent.

[0179] The additional therapeutically active component(s) may be administered to a subject prior to administration of an anti-C5 antibody of the present invention. For example, a first component may be deemed to be administered "prior to" a second component if the first component is administered 1 week before, 72 hours before, 60 hours before, 48 hours before, 36 hours before, 24 hours before, 12 hours before, 6 hours before, 5 hours before, 4 hours before, 3 hours before, 2 hours before, 1 hour before, 30 minutes before, 15 minutes before, 10 minutes before, 5 minutes before, or less than 1 minute before administration of the second component. In other embodiments, the additional therapeutically active component(s) may be administered to a subject after administration of an anti-C5 antibody of the present invention. For example, a first component may be deemed to be administered "after" a second component if the first component is administered 1 minute after, 5 minutes after, 10 minutes after, 15 minutes after, 30 minutes after, 1 hour after, 2 hours after, 3 hours after, 4 hours after, 5 hours after, 6 hours after, 12 hours after, 24 hours after, 36 hours after, 48 hours after, 60 hours after, 72 hours after administration of the second component. In yet other embodiments, the additional therapeutically active component(s) may be administered to a subject concurrent with administration of an anti-C5 antibody of the present invention. "Concurrent" administration, for purposes of the present invention, includes, *e.g.*, administration of an anti-C5 antibody and an additional therapeutically active component to a subject in a single dosage form, or in separate dosage forms administered to the subject within about 30 minutes or less of each other. If administered in separate dosage forms, each dosage form may be administered via the same route (*e.g.*, both the anti-C5 antibody and the additional therapeutically active component may be administered intravenously, etc.); alternatively, each dosage form may be administered via a different route (*e.g.*, the anti-C5 antibody may be administered intravenously, and the additional therapeutically active component may be administered orally). In any event, administering the components in a single dosage form, in separate dosage forms by the same route, or in separate dosage forms by different routes are all considered "concurrent

administration," for purposes of the present disclosure. For purposes of the present disclosure, administration of an anti-C5 antibody "prior to", "concurrent with," or "after" (as those terms are defined herein above) administration of an additional therapeutically active component is considered administration of an anti-C5 antibody "in combination with" an additional therapeutically active component.

[0180] The present invention includes pharmaceutical compositions in which an anti-C5 antibody of the present invention is co-formulated with one or more of the additional therapeutically active component(s) as described elsewhere herein.

Administration Regimens

[0181] According to certain embodiments, a single dose of an anti-C5 antibody of the invention (or a pharmaceutical composition comprising a combination of an anti-C5 antibody and any of the additional therapeutically active agents mentioned herein) may be administered to a subject in need thereof. According to certain embodiments of the present invention, multiple doses of an anti-C5 antibody (or a pharmaceutical composition comprising a combination of an anti-C5 antibody and any of the additional therapeutically active agents mentioned herein) may be administered to a subject over a defined time course. The methods according to this aspect of the invention comprise sequentially administering to a subject multiple doses of an anti-C5 antibody of the invention. As used herein, "sequentially administering" means that each dose of anti-C5 antibody is administered to the subject at a different point in time, *e.g.*, on different days separated by a predetermined interval (*e.g.*, hours, days, weeks or months). The present invention includes methods which comprise sequentially administering to the patient a single initial dose of an anti-C5 antibody, followed by one or more secondary doses of the anti-C5 antibody, and optionally followed by one or more tertiary doses of the anti-C5 antibody.

[0182] The terms "initial dose," "secondary doses," and "tertiary doses," refer to the temporal sequence of administration of the anti-C5 antibody of the invention. Thus, the "initial dose" is the dose which is administered at the beginning of the treatment regimen (also referred to as the "baseline dose"); the "secondary doses" are the doses which are administered after the initial dose; and the "tertiary doses" are the doses which are administered after the secondary doses. The initial, secondary, and tertiary doses may all contain the same amount of anti-C5 antibody, but generally may differ from one another in terms of frequency of administration. In certain embodiments,

however, the amount of anti-C5 antibody contained in the initial, secondary and/or tertiary doses varies from one another (*e.g.*, adjusted up or down as appropriate) during the course of treatment. In certain embodiments, two or more (*e.g.*, 2, 3, 4, or 5) doses are administered at the beginning of the treatment regimen as "loading doses" followed by subsequent doses that are administered on a less frequent basis (*e.g.*, "maintenance doses").

[0183] In certain exemplary embodiments of the present invention, each secondary and/or tertiary dose is administered 1 to 48 hours (*e.g.*, 1, 1½, 2, 2½, 3, 3½, 4, 4½, 5, 5½, 6, 6½, 7, 7½, 8, 8½, 9, 9½, 10, 10½, 11, 11½, 12, 12½, 13, 13½, 14, 14½, 15, 15½, 16, 16½, 17, 17½, 18, 18½, 19, 19½, 20, 20½, 21, 21½, 22, 22½, 23, 23½, 24, 24½, 25, 25½, 26, 26½, or more) after the immediately preceding dose. The phrase "the immediately preceding dose," as used herein, means, in a sequence of multiple administrations, the dose of anti-C5 antibody which is administered to a patient prior to the administration of the very next dose in the sequence with no intervening doses.

[0184] The methods according to this aspect of the invention may comprise administering to a patient any number of secondary and/or tertiary doses of an anti-C5 antibody. For example, in certain embodiments, only a single secondary dose is administered to the patient. In other embodiments, two or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, or more) secondary doses are administered to the patient. Likewise, in certain embodiments, only a single tertiary dose is administered to the patient. In other embodiments, two or more (*e.g.*, 2, 3, 4, 5, 6, 7, 8, or more) tertiary doses are administered to the patient.

[0185] In certain embodiments of the invention, the frequency at which the secondary and/or tertiary doses are administered to a patient can vary over the course of the treatment regimen. The frequency of administration may also be adjusted during the course of treatment by a physician depending on the needs of the individual patient following clinical examination.

Diagnostic Uses of the Antibodies

[0186] The anti-C5 antibodies of the present invention may be used to detect and/or measure C5 in a sample, *e.g.*, for diagnostic purposes. Some embodiments contemplate the use of one or more antibodies of the present invention in assays to detect a C5-associated-disease or disorder. Exemplary diagnostic assays for C5 may comprise, *e.g.*, contacting a sample, obtained from a patient, with an anti-C5 antibody of the invention,

wherein the anti-C5 antibody is labeled with a detectable label or reporter molecule or used as a capture ligand to selectively isolate C5 from patient samples. Alternatively, an unlabeled anti-C5 antibody can be used in diagnostic applications in combination with a secondary antibody which is itself detectably labeled. The detectable label or reporter molecule can be a radioisotope, such as ^3H , ^{14}C , ^{32}P , ^{35}S , or ^{125}I ; a fluorescent or chemiluminescent moiety such as fluorescein isothiocyanate, or rhodamine; or an enzyme such as alkaline phosphatase, β -galactosidase, horseradish peroxidase, or luciferase. Specific exemplary assays that can be used to detect or measure C5 in a sample include enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA), and fluorescence-activated cell sorting (FACS).

[0187] Samples that can be used in C5 diagnostic assays according to the present invention include any tissue or fluid sample obtainable from a patient, which contains detectable quantities of either C5 protein, or fragments thereof, under normal or pathological conditions. Generally, levels of C5 protein in a particular sample obtained from a healthy patient (*e.g.*, a patient not afflicted with a disease associated with C5) will be measured to initially establish a baseline, or standard, level of C5. This baseline level of C5 can then be compared against the levels of C5 measured in samples obtained from individuals suspected of having a C5-associated condition, or symptoms associated with such condition.

[0188] The antibodies specific for C5 protein may contain no additional labels or moieties, or they may contain an N-terminal or C-terminal label or moiety. In one embodiment, the label or moiety is biotin. In a binding assay, the location of a label (if any) may determine the orientation of the peptide relative to the surface upon which the peptide is bound. For example, if a surface is coated with avidin, a peptide containing an N-terminal biotin will be oriented such that the C-terminal portion of the peptide will be distal to the surface.

Selected Embodiments

[0189] Selected embodiments of the present disclosure include the following:

[0190] In Embodiment 1, the present invention includes an isolated antibody or antigen-binding fragment thereof that binds specifically to complement factor 5 (C5) protein, wherein the antibody or antigen-binding fragment thereof interacts with one or more amino acids contained within C5 (SEQ ID NO: 359), as determined by hydrogen/deuterium exchange.

[0191] In Embodiment 2, the present invention includes the isolated antibody of antigen-binding fragment of Embodiment 1, wherein the antibody or antigen-binding fragment thereof interacts with one or more amino acids contained within the alpha chain and/or the beta chain of C5, as determined by hydrogen/deuterium exchange.

[0192] In Embodiment 3, the present invention includes the isolated antibody of antigen-binding fragment of Embodiments 1 or 2, wherein the antibody or antigen-binding fragment thereof does not interact with an amino acid of the C5a anaphylatoxin region of C5, as determined by hydrogen/deuterium exchange.

[0193] In Embodiment 4, the present invention includes the isolated antibody of antigen-binding fragment of any one of Embodiments 1 to 3, wherein the antibody or antigen-binding fragment thereof interacts with one or more amino acids contained within SEQ ID NO: 360 and/or SEQ ID NO: 361, as determined by hydrogen/deuterium exchange.

[0194] In Embodiment 5, the present invention includes the isolated antibody or antigen-binding fragment of any one of Embodiments 1 to 4, wherein the antibody or antigen-binding fragment thereof interacts with an amino acid sequence selected from the group consisting of (a) amino acids 591 to 599 of SEQ ID NO: 359; (b) amino acids 593 to 599 of SEQ ID NO: 359; (c) amino acids 775 to 787 of SEQ ID NO: 359; (d) amino acids 775 to 794 of SEQ ID NO: 359; and (e) amino acids 779 to 787 of SEQ ID NO: 359.

[0195] In Embodiment 6, the present invention includes the isolated antibody or antigen-binding fragment thereof of any one of Embodiments 1 to 5, wherein the antibody or antigen-binding fragment thereof interacts with at least five amino acids contained within an amino acid sequence selected from the group consisting of SEQ ID NOs: 360 and 361.

[0196] In Embodiment 7, the present invention includes the isolated antibody or antigen-binding fragment thereof of any one of Embodiments 1 to 5, wherein the antibody or antigen-binding fragment thereof interacts with the amino acid sequences of SEQ ID NOs: 360 and 361.

[0197] In Embodiment 8, the present invention includes an isolated antibody or antigen-binding fragment thereof that binds specifically to complement factor 5 (C5) protein, wherein the antibody or antigen-binding fragment thereof interacts with at least one of the following amino acid residues: N591, M592, A593, T594, G595, M596, D597, S598, W599, W775, E776, V777, H778, L779, V780, P781, R782, R783, K784,

Q785, L786, Q787, F788, A789, L790, P791, D792, S793, or L794 of SEQ ID NO: 359.

[0198] In Embodiment 9, the present invention includes the isolated antibody or antigen-binding fragment thereof of any one of Embodiments 1 to 8, wherein the antibody has one or more of the following characteristics: (a) has serum concentration of more than 10 $\mu\text{g/mL}$ through day 70 upon administration to cynomolgus monkey; (b) blocks classical pathway (CP) hemolysis through day 35 upon administration to cynomolgus monkey, as measured in an *ex vivo* hemolysis assay; (c) blocks alternative pathway (AP) hemolysis through day 35 upon administration to cynomolgus monkey, as measured in an *ex vivo* hemolysis assay; (d) has serum half-life of more than 10 days in cynomolgus monkey; (e) has serum concentration of more than 10 $\mu\text{g/mL}$ through day 40 upon administration to C5-humanized mice; (f) blocks CP hemolysis through day 30 upon administration to C5-humanized mice, as measured in an *ex vivo* hemolysis assay; and (g) has serum half-life of more than 10 days in C5-humanized mice.

[0199] In Embodiment 10, the present invention includes the isolated antibody or antigen-binding fragment thereof of any one of Embodiments 1 to 9, wherein the antibody has an additional characteristic selected from the group consisting of: (a) is a fully human monoclonal antibody; (b) binds to human C5 with a dissociation constant (K_D) of less than 0.9nM at 25°C, as measured in a surface plasmon resonance assay; (c) binds to human C5 with a K_D of less than 0.3nM at 37°C, as measured in a surface plasmon resonance assay; (d) binds to monkey C5 with a K_D of less than 65nM, as measured in a surface plasmon resonance assay; (e) binds to human C5 variant R885H (SEQ ID NO: 356) with a K_D of less than 0.5nM, as measured in a surface plasmon resonance assay; (f) binds to human C5 variant R885C (SEQ ID NO: 357) with a K_D of less than 0.5nM, as measured in a surface plasmon resonance assay; (g) blocks human C5-mediated classical pathway (CP) hemolysis by more than 95% and with IC_{50} less than 6nM, as measured in a CP hemolysis assay; (h) blocks human C5-mediated alternative pathway (AP) hemolysis by more than 70% and with IC_{50} less than 165nM, as measured in a AP hemolysis assay; (i) inhibits African green monkey C5-mediated CP hemolysis with IC_{50} less than 185nM, as measured in a CP hemolysis assay; (j) inhibits African green monkey C5-mediated AP hemolysis with IC_{50} less than 235nM, as measured in a AP hemolysis assay; (k) inhibits cynomolgus monkey C5-mediated CP hemolysis with IC_{50} less than 145nM, as measured in a CP hemolysis assay; and (l)

inhibits cynomolgus monkey C5-mediated AP hemolysis with IC₅₀ less than 30nM, as measured in a AP hemolysis assay.

[0200] In Embodiment 11, the present invention includes the isolated antibody or antigen-binding fragment of any one of Embodiments 1 to 10, wherein the antibody or antigen-binding fragment comprises three heavy chain complementarity determining regions (CDRs) (HCDR1, HCDR2 and HCDR3) contained within any one of the heavy chain variable region (HCVR) sequences listed in Table 1; and three light chain CDRs (LCDR1, LCDR2 and LCDR3) contained within any one of the light chain variable region (LCVR) sequences listed in Table 1.

[0201] In Embodiment 12, the present invention includes the isolated antibody or antigen-binding fragment thereof of any one of Embodiments 1 to 11, comprising: (a) a HCDR1 domain having an amino acid sequence selected from the group consisting of SEQ ID NOs: 4, 20, 36, 52, 68, 84, 100, 124, 140, 148, 156, 172, 188, 204, 220, 236, 252, 268, 276, 292, 308, 324, and 340; (b) a HCDR2 domain having an amino acid sequence selected from the group consisting of SEQ ID NOs: 6, 22, 38, 54, 70, 86, 102, 126, 142, 150, 158, 174, 190, 206, 222, 238, 254, 270, 278, 294, 310, 326, and 342; (c) a HCDR3 domain having an amino acid sequence selected from the group consisting of SEQ ID NOs: 8, 24, 40, 56, 72, 88, 104, 128, 144, 152, 160, 176, 192, 208, 224, 240, 256, 272, 280, 296, 312, 328, and 344; (d) a LCDR1 domain having an amino acid sequence selected from the group consisting of SEQ ID NOs: 12, 28, 44, 60, 76, 92, 108, 116, 132, 164, 180, 196, 212, 228, 244, 260, 284, 300, 316, 332, and 348; (e) a LCDR2 domain having an amino acid sequence selected from the group consisting of SEQ ID NOs: 14, 30, 46, 62, 78, 94, 110, 118, 134, 166, 182, 198, 214, 230, 246, 262, 286, 302, 318, 334, and 350; and (f) a LCDR3 domain having an amino acid sequence selected from the group consisting of SEQ ID NOs: 16, 32, 48, 64, 80, 96, 112, 120, 136, 168, 184, 200, 216, 232, 248, 264, 288, 304, 320, 336, and 352.

[0202] In Embodiment 13, the present invention includes the isolated antibody or antigen-binding fragment thereof of any one of Embodiments 1 to 12 comprising a HCVR having an amino acid sequence selected from the group consisting of HCVR sequences listed in Table 1.

[0203] In Embodiment 14, the present invention includes an isolated antibody or antigen-binding fragment thereof of Embodiment 13 comprising a LCVR having an amino acid sequence selected from the group consisting of LCVR sequences listed in Table 1.

[0204] In Embodiment 15, the present invention includes the isolated antibody or antigen-binding fragment of any one of Embodiments 11 to 14 comprising a HCVR/LCVR amino acid sequence pair selected from the group consisting of SEQ ID NOs: 2/10, 18/26, 34/42, 50/58, 66/74, 82/90, 98/106, 98/114, 122/106, 98/130, 138/106, 146/106, 122/130, 146/114, 146/130, 138/130, 154/162, 170/178, 186/194, 202/210, 218/226, 234/242, 250/258, 266/258, 274/282, 290/298, 306/314, 322/330, and 338/346.

[0205] In Embodiment 16, the present invention includes the isolated antibody or antigen-binding fragment thereof of any one of Embodiments 11 to 15 comprising three CDRs contained within a HCVR selected from the group consisting of SEQ ID NOs: 50, 98, 138, and 202; and three CDRs contained within a LCVR selected from the group consisting of SEQ ID NOs: 58, 106, and 210.

[0206] In Embodiment 17, the present invention includes the isolated antibody or antigen-binding fragment thereof of Embodiment 16 comprising CDRs selected from the group consisting of: (a) SEQ ID NOs: 52, 54, 56, 60, 62, and 64; (b) SEQ ID NOs: 100, 102, 104, 108, 110, and 112; (c) SEQ ID NOs: 140, 142, 144, 108, 110, and 112; and (d) SEQ ID NOs: 204, 206, 208, 212, 214, and 216.

[0207] In Embodiment 18, the present invention includes the isolated antibody or antigen-binding fragment thereof of Embodiment 17 comprising a HCVR/LCVR amino acid sequence pair selected from the group consisting of SEQ ID NOs: 50/58, 98/106, 138/106, and 202/210.

[0208] In Embodiment 19, the present invention includes an antibody or antigen-binding fragment thereof that competes for binding to C5 with the antibody or antigen-binding fragment thereof of Embodiment 17.

[0209] In Embodiment 20, the present invention includes an antibody or antigen-binding fragment thereof that binds to the same epitope as an antibody or antigen-binding fragment thereof of Embodiment 17.

[0210] In Embodiment 21, the present invention includes the antibody or antigen-binding fragment thereof of Embodiment 9 or 10 comprising a heavy chain variable region comprising an amino acid sequence listed in Table 1 having no more than 5 amino acid substitutions.

[0211] In Embodiment 22, the present invention includes the antibody or antigen-binding fragment thereof of Embodiment 21, comprising a light chain variable region

comprising an amino acid sequence listed in Table 1 having no more than 5 amino acid substitutions.

[0212] In Embodiment 23, the present invention includes the antibody or antigen-binding fragment thereof of Embodiment 9 or 10 comprising a heavy chain variable region having at least 90% sequence identity to SEQ ID NO: 98.

[0213] In Embodiment 24, the present invention includes an antibody or antigen-binding fragment thereof of Embodiment 23 comprising a light chain variable region having at least 90% sequence identity to SEQ ID NO: 106.

[0214] In Embodiment 25, the present invention includes an isolated monoclonal antibody or antigen-binding fragment thereof that blocks C5 cleavage to C5a and C5b comprising three CDRs of a HCVR, wherein the HCVR has an amino acid sequence selected from the group consisting of SEQ ID NOs: 2, 18, 34, 50, 66, 82, 98, 122, 138, 146, 154, 170, 186, 202, 218, 234, 250, 266, 274, 290, 306, 322, and 338; and three CDRs of a LCVR, wherein the LCVR has an amino acid sequence selected from the group consisting of SEQ ID NOs: 10, 26, 42, 58, 74, 90, 106, 114, 130, 162, 178, 194, 210, 226, 242, 258, 282, 298, 314, 330, and 346.

[0215] In Embodiment 26, the present invention includes a pharmaceutical composition comprising an isolated antibody or antigen-binding fragment thereof that binds to C5 according to any one of Embodiments 1 to 25 and a pharmaceutically acceptable carrier or diluent.

[0216] In Embodiment 27, the present invention includes an isolated polynucleotide molecule comprising a polynucleotide sequence that encodes a HCVR of an antibody as set forth in any one of Embodiments 1 to 25.

[0217] In Embodiment 28, the present invention includes an isolated polynucleotide molecule comprising a polynucleotide sequence that encodes a LCVR of an antibody as set forth in any one of Embodiments 1 to 25.

[0218] In Embodiment 29, the present invention includes a vector comprising the polynucleotide sequence of Embodiment 27 or 28.

[0219] In Embodiment 30, the present invention includes a cell expressing the vector of Embodiment 29.

[0220] In Embodiment 31, the present invention includes a method of preventing, treating or ameliorating at least one symptom or indication of a disease or disorder associated with C5, the method comprising administering an antibody or antigen-binding fragment of any one of Embodiments 1 to 25 to a subject in need thereof.

[0221] In Embodiment 32, the present invention includes the method of Embodiment 31, wherein the disease or disorder is selected from the group consisting of atypical hemolytic uremic syndrome (aHUS), paroxysmal nocturnal hemoglobinuria (PNH), age-related macular degeneration, geographic atrophy, uveitis, neuromyelitis optica, multiple sclerosis, stroke, Guillain Barre Syndrome, traumatic brain injury, Parkinson's disease, disorders of inappropriate or undesirable complement activation, hemodialysis complications, hyperacute allograft rejection, xenograft rejection, interleukin-2 induced toxicity during IL-2 therapy, inflammatory disorders, inflammation of autoimmune diseases, Crohn's disease, adult respiratory distress syndrome, thermal injury including burns or frostbite, post-ischemic reperfusion conditions, myocardial infarction, capillary leak syndrome, obesity, diabetes, Alzheimer's disease, schizophrenia, stroke, epilepsy, atherosclerosis, vasculitis, bullous pemphigoid, C3 glomerulopathy, membranoproliferative glomerulonephritis, diabetic nephropathy, Alport's syndrome, progressive kidney failure, proteinuric kidney diseases, renal ischemia-reperfusion injury, lupus nephritis, balloon angioplasty, post-pump syndrome in cardiopulmonary bypass or renal bypass, hemodialysis, renal ischemia, mesenteric artery reperfusion after aortic reconstruction, infectious disease or sepsis, immune complex disorders and autoimmune diseases, renal disorders, rheumatoid arthritis, systemic lupus erythematosus (SLE), SLE nephritis, proliferative nephritis, hemolytic anemia, asthma, chronic obstructive pulmonary disease (COPD), emphysema, pulmonary embolisms and infarcts, pneumonia, and myasthenia gravis.

[0222] In Embodiment 33, the present invention includes the method of Embodiment 31, wherein the disease or disorder is aHUS.

[0223] In Embodiment 34, the present invention includes the method of Embodiment 31, wherein the disease or disorder is PNH.

[0224] In Embodiment 35, the present invention includes the method of any one of Embodiments 31 – 34, wherein the pharmaceutical composition is administered prophylactically or therapeutically to the subject in need thereof.

[0225] In Embodiment 36, the present invention includes the method of any one of Embodiments 31 to 35, wherein the pharmaceutical composition is administered in combination with a second therapeutic agent.

[0226] In Embodiment 37, the present invention includes the method of Embodiment 36, wherein the second therapeutic agent is selected from the group consisting of an anti-coagulant, an anti-inflammatory drug, an antihypertensive, an immunosuppressive

agent, a lipid-lowering agent, an anti-CD20 agent such as rituximab, an anti-TNF agent such as infliximab, an anti-seizure agent, a C3 inhibitor, a second anti-C5 antibody, and an anti-thrombotic agent.

[0227] In Embodiment 38, the present invention includes the method of any one of Embodiments 31 to 37, wherein the pharmaceutical composition is administered subcutaneously, intravenously, intradermally, intraperitoneally, orally, intramuscularly or intracranially.

EXAMPLES

[0228] The following examples are put forth so as to provide those of ordinary skill in the art with a complete disclosure and description of how to make and use the methods and compositions of the invention, and are not intended to limit the scope of what the inventors regard as their invention. Efforts have been made to ensure accuracy with respect to numbers used (*e.g.*, amounts, temperature, etc.) but some experimental errors and deviations should be accounted for. Unless indicated otherwise, parts are parts by weight, molecular weight is average molecular weight, temperature is in degrees Centigrade, room temperature is about 25°C, and pressure is at or near atmospheric.

Example 1: Generation of Human Antibodies to Complement Factor 5 (C5) protein

[0229] Human antibodies to C5 protein were generated in a VELOCIMMUNE[®] mouse comprising DNA encoding human Immunoglobulin heavy and kappa light chain variable regions. The mice were immunized with serum purified human C5 protein (Calbiochem Cat #20-4888).

[0230] The antibody immune response was monitored by a C5-specific immunoassay. When a desired immune response was achieved splenocytes were harvested and fused with mouse myeloma cells to preserve their viability and form hybridoma cell lines. The hybridoma cell lines were screened and selected to identify cell lines that produce C5-specific antibodies. The cell lines were used to obtain several anti-C5 chimeric antibodies (*i.e.*, antibodies possessing human variable domains and mouse constant domains); exemplary antibodies generated in this manner were designated as H2M11683N and H2M11686N.

[0231] Anti-C5 antibodies were also isolated directly from antigen-positive mouse B cells without fusion to myeloma cells, as described in U.S. Patent 7582298, herein

specifically incorporated by reference in its entirety. Using this method, several fully human anti-C5 antibodies (*i.e.*, antibodies possessing human variable domains and human constant domains) were obtained; exemplary antibodies generated in this manner were designated as H4H12159P, H4H12161P, H4H12163P, H4H12164P, H4H12166P, H4H12167P, H4H12168P, H4H12169P, H4H12170P, H4H12171P, H4H12175P, H4H12176P2, H4H12177P2 and H4H12183P2.

[0232] The biological properties of the exemplary antibodies generated in accordance with the methods of this Example are described in detail in the Examples set forth below.

Example 2: Heavy and Light Chain Variable Region Amino Acid and Nucleotide Sequences

[0233] Table 1 sets forth the amino acid sequence identifiers of the heavy and light chain variable regions and CDRs of selected anti-C5 antibodies of the invention.

Table 1: Amino Acid Sequence Identifiers

Antibody Designation	SEQ ID NOs:							
	HCVR	HCDR1	HCDR2	HCDR3	LCVR	LCDR1	LCDR2	LCDR3
H2M11683N	2	4	6	8	10	12	14	16
H2M11686N	18	20	22	24	26	28	30	32
H4H12159P	34	36	38	40	42	44	46	48
H4H12161P	50	52	54	56	58	60	62	64
H4H12163P	66	68	70	72	74	76	78	80
H4H12164P	82	84	86	88	90	92	94	96
H4H12166P	98	100	102	104	106	108	110	112
H4H12166P2	98	100	102	104	114	116	118	120
H4H12166P3	122	124	126	128	106	108	110	112
H4H12166P4	98	100	102	104	130	132	134	136
H4H12166P5	138	140	142	144	106	108	110	112
H4H12166P6	146	148	150	152	106	108	110	112
H4H12166P7	122	124	126	128	130	132	134	136
H4H12166P8	146	148	150	152	114	116	118	120
H4H12166P9	146	148	150	152	130	132	134	136
H4H12166P10	138	140	142	144	130	132	134	136
H4H12167P	154	156	158	160	162	164	166	168

H4H12168P	170	172	174	176	178	180	182	184
H4H12169P	186	188	190	192	194	196	198	200
H4H12170P	202	204	206	208	210	212	214	216
H4H12171P	218	220	222	224	226	228	230	232
H4H12175P	234	236	238	240	242	244	246	248
H4H12176P2	250	252	254	256	258	260	262	264
H4H12177P2	266	268	270	272	258	260	262	264
H4H12183P2	274	276	278	280	282	284	286	288
H2M11682N	290	292	294	296	298	300	302	304
H2M11684N	306	308	310	312	314	316	318	320
H2M11694N	322	324	326	328	330	332	334	336
H2M11695N	338	340	342	344	346	348	350	352

[0234] The corresponding nucleic acid sequence identifiers are set forth in Table 2.

Table 2: Nucleic Acid Sequence Identifiers

Antibody Designation	SEQ ID NOs:							
	HCVR	HCDR1	HCDR2	HCDR3	LCVR	LCDR1	LCDR2	LCDR3
H2M11683N	1	3	5	7	9	11	13	15
H2M11686N	17	19	21	23	25	27	29	31
H4H12159P	33	35	37	39	41	43	45	47
H4H12161P	49	51	53	55	57	59	61	63
H4H12163P	65	67	69	71	73	75	77	79
H4H12164P	81	83	85	87	89	91	93	95
H4H12166P	97	99	101	103	105	107	109	111
H4H12166P2	97	99	101	103	113	115	117	119
H4H12166P3	121	123	125	127	105	107	109	111
H4H12166P4	97	99	101	103	129	131	133	135
H4H12166P5	137	139	141	143	105	107	109	111
H4H12166P6	145	147	149	151	105	107	109	111
H4H12166P7	121	123	125	127	129	131	133	135
H4H12166P8	145	147	149	151	113	115	117	119
H4H12166P9	145	147	149	151	129	131	133	135
H4H12166P10	137	139	141	143	129	131	133	135
H4H12167P	153	155	157	159	161	163	165	167
H4H12168P	169	171	173	175	177	179	181	183
H4H12169P	185	187	189	191	193	195	197	199

H4H12170P	201	203	205	207	209	211	213	215
H4H12171P	217	219	221	223	225	227	229	231
H4H12175P	233	235	237	239	241	243	245	247
H4H12176P2	249	251	253	255	257	259	261	263
H4H12177P2	265	267	269	271	257	259	261	263
H4H12183P2	273	275	277	279	281	283	285	287
H2M11682N	289	291	293	295	297	299	301	303
H2M11684N	305	307	309	311	313	315	317	319
H2M11694N	321	323	325	327	329	331	333	335
H2M11695N	337	339	341	343	345	347	349	351

[0235] Antibodies are typically referred to herein according to the following nomenclature: Fc prefix (*e.g.* "H4H," "H2M," etc.), followed by a numerical identifier (*e.g.* "11686," "12166," "12183," etc., as shown in Table 2), followed by a "P," "P2," or "N" suffix. Thus, according to this nomenclature, an antibody may be referred to herein as, *e.g.*, "H2M11686N," "H4H12183P2," "H4H12168P," etc. The H4H and H2M prefixes on the antibody designations used herein indicate the particular Fc region isotype of the antibody. For example, an "H4H" antibody has a human IgG4 Fc comprising a serine to proline mutation in the hinge region (S108P) to promote dimer stabilization, and an "H2M" antibody has a mouse IgG2 Fc (a or b isotype) (all variable regions are fully human as denoted by the first 'H' in the antibody designation). As will be appreciated by a person of ordinary skill in the art, an antibody having a particular Fc isotype can be converted to an antibody with a different Fc isotype (*e.g.*, an antibody with a mouse IgG1 Fc can be converted to an antibody with a human IgG4, etc.), but in any event, the variable domains (including the CDRs) – which are indicated by the numerical identifiers shown in Table 2 – will remain the same, and the binding properties to antigen are expected to be identical or substantially similar regardless of the nature of the Fc domain.

[0236] In certain embodiments, selected antibodies with a mouse IgG1 Fc were converted to antibodies with human IgG4 Fc. In one embodiment, the IgG4 Fc domain comprises 2 or more amino acid changes as disclosed in US20100331527.

[0237] To generate mutated antibodies, various residues in the complementary determining regions (CDRs) of H4H12166P were mutated to histidine to generate 9 mutated antibodies, identified as H4H12166P2 to H4H12166P10. Histidine mutations in the CDRs have been shown to confer pH-dependence of binding to target antigen

leading to improved pharmacokinetics (Igawa *et al.* 2010, Nat. Biotechnol. 28: 1203-1207).

Control Constructs used in the Following Examples

[0238] The following control constructs (anti-C5 antibodies) were included in the experiments disclosed herein, for comparative purposes: "Comparator 1," a monoclonal antibody against human C5 having V_H/V_L sequences of antibody "h5G1.1" according to US Patent No. 6,355,245 (Alexion Pharmaceuticals, Inc.); and "Comparator 2," a human monoclonal antibody against human C5 having V_H/V_L sequences of antibody "8109" according to US Patent Application Publication No. 2013/0022615 (Novartis).

Example 3: Antibody binding to C5 as determined by Surface Plasmon Resonance

[0239] Equilibrium dissociation constants (K_D values) for C5 binding to purified anti-C5 antibodies were determined using a real-time surface plasmon resonance biosensor assay on a Biacore T200 instrument. The Biacore sensor surface was derivatized by amine coupling with a monoclonal mouse anti-human Fc antibody (GE Healthcare, # BR-1008-39) to capture anti-C5 antibodies expressed with human Fc constant regions. Biacore binding studies were conducted in HBST running buffer (0.01M HEPES pH 7.4, 0.15M NaCl, 3mM EDTA, 0.05% v/v Surfactant P20). Human C5 was obtained from a commercial source (EMD). Other C5 reagents were expressed with a C-terminal myc-myc-hexahistidine tag (subsequently referred to as C5-mmh). Human C5-mmh reagents were also expressed containing histidine and cysteine point mutations at arginine 885 (subsequently referred to as C5 R885H-mmh and C5 R885C-mmh, respectively). Different concentrations of human C5, human C5 R885H-mmh (SEQ ID No: 356), human C5 R885C-mmh (SEQ ID No: 357) and monkey C5-mmh (SEQ ID No: 358) (ranging from 100 nM to 1.23 nM, 3-fold dilutions) prepared in HBST running buffer were injected over the anti-C5 antibody captured surface at a flow rate of 30 μ L/min. Association of all the C5 reagents to each of the captured monoclonal antibodies was monitored for 3 minutes and their dissociation in HBST running buffer was monitored for 8 minutes. All the binding kinetics experiments were performed at either 25°C or 37°C. Kinetic association (k_a) and dissociation (k_d) rate constants were determined by fitting the real-time sensorgrams to a 1:1 binding model using Scrubber 2.0c curve fitting software. Binding dissociation equilibrium constants

(K_D) and dissociative half-lives ($t_{1/2}$) were calculated from the kinetic rate constants as:

$$K_D \text{ (M)} = k_d/k_a \text{ and } t_{1/2} \text{ (min)} = \ln 2 / (60 \times k_d)$$

[0240] Binding kinetic parameters for human C5 binding to anti-C5 antibodies at 25°C and 37°C are shown in Tables 3 and 4.

Table 3: Binding Kinetics parameters of anti-C5 monoclonal antibodies binding to human C5 at 25°C

Antibody	Amount of Antibody Captured (RU)	100nM Human C5 Bound (RU)	k_a	k_d	K_D	$t_{1/2}$
			(1/Ms)	(1/s)	(M)	(min)
H4H11683N	231	439	4.17E+05	5.14E-05	1.23E-10	225
H4H12171P	51	64	1.49E+05	8.16E-05	5.49E-10	142
H4H12161P	38	64	2.58E+05	4.37E-05	1.70E-10	264
H4H12176P2	50	96	3.36E+05	6.75E-05	2.01E-10	171
H4H12163P	51	108	6.43E+05	2.08E-04	3.24E-10	55
H4H12167P	52	116	1.09E+06	1.31E-04	1.21E-10	88
H4H12175P	51	100	2.16E+05	1.96E-04	9.10E-10	59
H4H12159P	53	118	9.75E+05	7.13E-05	7.31E-11	162
H4H12164P	52	103	2.92E+05	8.84E-05	3.02E-10	131
H4H12168P	50	113	4.23E+05	4.75E-05	1.12E-10	243
H4H12169P	51	18	2.24E+05	4.40E-04	1.96E-09	26
H4H11686N	200	341	2.20E+05	3.31E-05	1.50E-10	349
H4H12170P	51	119	5.25E+05	6.79E-05	1.29E-10	170
H4H12177P2	47	60	6.56E+04	6.29E-05	9.59E-10	184
H4H12183P2	46	50	1.66E+05	2.70E-05	1.63E-10	427
H4H12166P	53	105	6.42E+05	1.10E-04	1.71E-10	105
H4H12166P2	53	95	8.26E+05	3.61E-04	4.38E-10	32
H4H12166P3	59	124	4.03E+05	4.65E-04	1.15E-09	25
H4H12166P4	49	92	4.46E+05	1.76E-04	3.95E-10	66
H4H12166P5	59	110	2.85E+05	3.28E-04	1.15E-09	35
H4H12166P6	64	131	4.89E+05	1.84E-04	3.75E-10	63
H4H12166P7	50	92	2.74E+05	1.01E-03	3.67E-09	11
H4H12166P8	50	91	4.84E+05	6.86E-04	1.42E-09	17
H4H12166P9	52	100	3.32E+05	2.64E-04	7.94E-10	44
H4H12166P10	49	69	1.57E+05	1.32E-03	8.38E-09	9
Comparator 1	232	250	9.69E+04	1.46E-04	1.51E-09	79
Comparator 2	117	170	2.62E+05	2.39E-04	9.12E-10	48

Table 4: Binding Kinetics parameters of anti-C5 monoclonal antibodies binding to human C5 at 37°C

Antibody	Amount of Antibody Captured (RU)	100nM Human C5 Bound (RU)	k_a	k_d	K_D	$t_{1/2}$
			(1/Ms)	(1/s)	(M)	(min)
H4H11683N	257	492	4.54E+05	2.41E-04	5.32E-10	48
H4H12171P	59	58	1.22E+05	7.62E-04	6.27E-09	15
H4H12161P	40	66	1.16E+05	1.15E-04	9.90E-10	101
H4H12176P2	38	71	1.47E+05	2.34E-04	1.59E-09	49
H4H12163P	65	139	9.11E+05	6.65E-04	7.29E-10	17
H4H12167P	75	153	1.29E+06	3.81E-04	2.95E-10	30
H4H12175P	74	132	2.96E+05	6.37E-04	2.15E-09	18
H4H12159P	70	145	1.04E+06	1.07E-04	1.03E-10	108
H4H12164P	66	140	3.96E+05	1.28E-04	3.23E-10	90
H4H12168P	34	12	2.50E+04	4.64E-04	1.85E-08	25
H4H12169P	59	65	1.15E+05	3.52E-04	3.06E-09	33
H4H11686N	206	406	3.33E+05	1.56E-04	4.69E-10	74
H4H12170P	34	55	2.97E+05	4.15E-04	1.40E-09	28
H4H12177P2	41	37	4.42E+04	5.78E-04	1.31E-08	20
H4H12183P2	29	30	4.30E+04	2.50E-04	5.81E-09	46
H4H12166P	69	127	8.80E+05	2.30E-04	2.62E-10	50
H4H12166P2	68	110	9.50E+05	1.23E-03	1.29E-09	9
H4H12166P3	86	147	6.12E+05	1.27E-03	2.07E-09	9
H4H12166P4	63	108	5.05E+05	4.69E-04	9.30E-10	25
H4H12166P5	76	129	4.40E+05	1.22E-03	2.77E-09	9
H4H12166P6	90	157	5.42E+05	4.74E-04	8.75E-10	24
H4H12166P7	64	105	3.49E+05	2.58E-03	7.39E-09	4
H4H12166P8	65	98	6.75E+05	2.09E-03	3.10E-09	6
H4H12166P9	76	122	3.75E+05	6.39E-04	1.70E-09	18
H4H12166P10	64	82	2.27E+05	3.14E-03	1.38E-08	4
Comparator 1	185	246	1.47E+05	5.30E-04	3.61E-09	22
Comparator 2	119	205	2.85E+05	6.57E-04	2.30E-10	18

[0241] Monkey C5-mmh binding to anti-C5 antibodies at 25°C and 37°C are shown in Tables 5 and 6.

Table 5: Binding Kinetics parameters of anti-C5 monoclonal antibodies binding to monkey C5-mmh at 25°C

Antibody	Amount of Antibody Captured (RU)	100nM monkey C5-mmh Bound (RU)	k_a (1/Ms)	k_d (1/s)	K_D (M)	$t_{1/2}$ (min)
H4H11683N	228	403	3.86E+05	2.47E-04	6.40E-10	47
H4H12171P	51	17	4.60E+04	2.26E-04	4.92E-09	51
H4H12161P	38	45	6.33E+04	2.48E-05	3.92E-10	465
H4H12176P2	50	69	1.82E+05	5.88E-05	3.22E-10	196
H4H12163P	50	98	3.11E+05	7.75E-04	2.49E-09	15
H4H12167P	52	111	4.19E+05	1.32E-04	3.15E-10	88
H4H12175P	51	59	6.42E+04	1.65E-03	2.57E-08	7
H4H12159P	53	116	3.54E+05	4.69E-05	1.33E-10	246
H4H12164P	51	66	1.27E+05	1.53E-03	1.20E-08	8
H4H12168P	50	86	1.73E+05	1.14E-04	6.60E-10	101
H4H12169P	51	22	1.64E+05	4.55E-03	2.78E-08	3
H4H11686N	196	247	1.57E+05	4.89E-04	3.11E-09	24
H4H12170P	51	92	2.62E+05	5.21E-05	1.99E-10	222
H4H12177P2	47	32	4.62E+04	9.92E-04	2.15E-08	12
H4H12183P2	47	23	4.88E+04	4.94E-04	1.01E-08	23
H4H12166P	52	90	2.05E+05	1.06E-03	5.15E-09	11
H4H12166P2	53	71	3.00E+05	3.16E-03	1.05E-08	4
H4H12166P3	59	72	1.68E+05	4.47E-03	2.66E-08	3
H4H12166P4	49	69	2.10E+05	1.78E-03	8.50E-09	6
H4H12166P5	59	56	1.44E+05	3.46E-03	2.40E-08	3
H4H12166P6	64	94	2.39E+05	2.66E-03	1.11E-08	4
H4H12166P7	50	36	1.36E+05	6.33E-03	4.65E-08	2
H4H12166P8	50	47	2.31E+05	4.99E-03	2.16E-08	2
H4H12166P9	52	55	1.70E+05	3.18E-03	1.87E-08	4
H4H12166P10	49	15	9.56E+04	6.16E-03	6.44E-08	2
Comparator 1*	228	11	N/A	N/A	3.11E-07	N/A

N/A= Not Available; *SS= steady state analysis

Table 6: Binding Kinetics parameters of anti-C5 monoclonal antibodies binding to monkey C5-mmh at 37°C

Antibody	Amount of Antibody Captured (RU)	100nM monkey C5-mmh Bound (RU)	<i>ka</i>	<i>kd</i>	KD	t _{1/2}
			(1/Ms)	(1/s)	(M)	(min)
H4H11683N	192	303	5.35E+05	1.15E-03	2.16E-09	10
H4H12171P	59	78	5.56E+05	1.03E-03	1.85E-09	11
H4H12161P	41	53	1.34E+05	7.45E-04	5.56E-09	16
H4H12176P2	36	47	1.35E+05	1.29E-03	9.60E-09	9
H4H12163P	64	129	3.90E+05	1.25E-03	3.20E-09	9
H4H12167P	74	146	5.37E+05	2.89E-04	5.39E-10	40
H4H12175P	74	74	1.77E+05	2.76E-03	1.56E-08	4
H4H12159P	70	137	4.12E+05	5.50E-05	1.33E-10	210
H4H12164P	65	99	1.86E+05	1.17E-03	6.30E-09	10
H4H12168P	34	29	5.33E+04	6.76E-04	1.27E-08	17
H4H12169P	59	64	2.51E+05	3.61E-03	1.43E-08	3
H4H11686N	145	195	2.33E+05	2.07E-03	8.88E-09	6
H4H12170P	34	60	5.21E+05	8.71E-04	1.67E-09	13
H4H12177P2	41	27	1.50E+05	7.17E-03	4.77E-08	2
H4H12183P2	28	13	5.40E+04	6.37E-03	1.18E-07	2
H4H12166P	68	110	2.19E+05	1.87E-03	8.55E-09	6
H4H12166P2	68	83	3.93E+05	2.97E-03	7.56E-09	4
H4H12166P3	85	92	2.23E+05	2.92E-03	1.31E-08	4
H4H12166P4	62	80	2.23E+05	1.83E-03	8.20E-09	6
H4H12166P5	75	70	1.50E+05	3.13E-03	2.09E-08	4
H4H12166P6	90	112	2.53E+05	2.32E-03	9.18E-09	5
H4H12166P7	63	48	1.25E+05	2.41E-03	1.93E-08	5
H4H12166P8	64	53	2.03E+05	2.69E-03	1.33E-08	4
H4H12166P9	75	69	1.81E+05	2.61E-03	1.44E-08	4
H4H12166P10	63	24	6.60E+04	2.79E-03	4.22E-08	4
Comparator 1	132	4	NB	NB	NB	NB

[0242] Human C5 R885H-mmh and human C5 R885C-mmh binding to anti-C5 antibodies at 25°C are shown in Tables 7 and 8, respectively.

Table 7: Binding Kinetics parameters of anti-C5 monoclonal antibodies binding to human C5 R885H-mmh at 25°C

Antibody	Amount of Antibody Captured (RU)	100nM Human C5 R885H-mmh Bound (RU)	k_a	k_d	K_D	$t_{1/2}$
			(1/Ms)	(1/s)	(M)	(min)
H4H11683N	183	118	5.26E+05	2.46E-04	4.68E-10	47
H4H12171P	119	51	6.59E+05	1.42E-04	2.16E-10	81
H4H12161P	105	199	8.36E+04	8.32E-05	9.96E-10	139
H4H12176P2	170	65	1.78E+05	2.17E-04	1.22E-09	53
H4H12163P	111	214	6.72E+05	4.34E-04	6.46E-10	27
H4H12167P	93	187	6.89E+05	2.98E-04	4.33E-10	39
H4H12175P	104	207	1.81E+05	1.98E-03	1.09E-08	6
H4H12159P	101	177	7.06E+05	1.76E-04	2.50E-10	66
H4H12164P	143	295	1.58E+05	1.87E-04	1.19E-09	62
H4H12168P	138	197	5.29E+04	2.14E-04	4.05E-09	54
H4H12169P	116	173	4.84E+05	7.09E-05	1.47E-10	163
H4H11686N	145	259	2.16E+05	1.06E-04	4.91E-10	109
H4H12170P	244	442	4.09E+05	1.61E-04	3.94E-10	72
H4H12177P2	137	232	1.48E+05	5.92E-04	4.01E-09	20
H4H12183P2	158	99	3.77E+04	4.37E-05	1.16E-09	264
H4H12166P	188	366	5.28E+05	2.12E-04	4.02E-10	54
Comparator 1	87	11	NB	NB	NB	NB
Comparator 2	118	249	1.08E+06	6.53E-04	6.06E-10	18

Table 8: Binding Kinetics parameters of anti-C5 monoclonal antibodies binding to human C5 R885C-mmh at 25°C

Antibody	Amount of Antibody Captured (RU)	100nM Human C5 R885C-mmh Bound (RU)	k_a	k_d	K_D	$t_{1/2}$
			(1/Ms)	(1/s)	(M)	(min)
H4H11683N	174	116	4.99E+05	2.39E-04	4.79E-10	48
H4H12171P	109	51	3.79E+05	1.39E-04	3.66E-10	83
H4H12161P	103	147	1.30E+05	8.71E-05	6.72E-10	133
H4H12176P2	164	63	1.07E+05	2.18E-04	2.03E-09	53
H4H12163P	110	211	5.04E+05	4.32E-04	8.58E-10	27

H4H12167P	85	163	7.11E+05	2.94E-04	4.13E-10	39
H4H12175P	99	128	8.18E+04	1.55E-02	1.90E-07	1
H4H12159P	93	168	5.86E+05	1.69E-04	2.89E-10	68
H4H12164P	139	249	1.53E+05	1.82E-04	1.19E-09	63
H4H12168P	128	144	6.09E+04	1.99E-04	3.27E-09	58
H4H12169P	108	168	2.78E+05	6.99E-05	2.51E-10	165
H4H11686N	143	253	1.78E+05	9.49E-05	5.34E-10	122
H4H12170P	244	427	3.57E+05	1.60E-04	4.47E-10	72
H4H12177P2	138	177	1.00E+05	1.32E-03	1.32E-08	9
H4H12183P2	158	80	2.99E+04	2.20E-05	7.37E-10	525
H4H12166P	188	356	4.26E+05	2.07E-04	4.87E-10	56
Comparator 1	87	9	NB	NB	NB	NB
Comparator 2	117	241	1.17E+06	6.19E-04	5.30E-10	19

[0243] Human C5 R885H-mmh and human C5 R885C-mmh binding to anti-C5 antibodies at 37°C are shown in Tables 9 and 10, respectively.

Table 9: Binding Kinetics parameters of anti-C5 monoclonal antibodies binding to human C5 R885H-mmh at 37°C

Antibody	Amount of Antibody Captured (RU)	100nM Human C5 R885H-mmh	k_a	k_d	K_D	$t_{1/2}$
		Bound (RU)	(1/Ms)	(1/s)	(M)	(min)
H4H11683N	49	81	5.48E+05	1.47E-03	2.69E-09	8
H4H12171P	59	80	5.92E+05	9.63E-04	1.63E-09	12
H4H12161P	41	54	1.18E+05	9.25E-04	7.84E-09	12
H4H12176P2	45	69	2.57E+05	9.58E-04	3.73E-09	12
H4H12163P	60	85	7.24E+05	2.90E-03	4.00E-09	4
H4H12167P	38	65	8.81E+05	2.57E-03	2.91E-09	5
H4H12175P	25	30	1.37E+05	9.50E-03	6.94E-08	1
H4H12159P	51	82	6.38E+05	9.48E-04	1.49E-09	12
H4H12164P	59	68	1.95E+05	1.06E-03	5.46E-09	11
H4H12168P	34	29	2.43E+04	1.23E-03	5.04E-08	9
H4H12169P	61	79	4.29E+05	7.39E-04	1.72E-09	16
H4H11686N	40	74	4.19E+05	8.00E-04	1.91E-09	14
H4H12170P	36	64	5.59E+05	8.39E-04	1.50E-09	14
H4H12177P2	45	51	2.76E+05	2.76E-03	1.00E-08	4
H4H12183P2	33	36	9.58E+04	7.12E-04	7.43E-09	16
H4H12166P	71	58	6.24E+05	1.31E-03	2.09E-09	9
Comparator 1	41	5	NB	NB	NB	NB
Comparator 2	23	47	8.39E+05	1.05E-03	1.25E-09	11

Table 10: Binding Kinetics parameters of anti-C5 monoclonal antibodies binding to human C5 R885C-mmh at 37°C

Antibody	Amount of Antibody Captured (RU)	100nM Human C5 R885C-mmh Bound (RU)	k_a	k_d	K_D	$t_{1/2}$
			(1/Ms)	(1/s)	(M)	(min)
H4H11683N	48	78	4.38E+05	1.43E-03	3.25E-09	8
H4H12171P	59	78	4.77E+05	9.57E-04	2.01E-09	12
H4H12161P	41	49	1.10E+05	9.01E-04	8.17E-09	13
H4H12176P2	44	55	1.41E+05	1.03E-03	7.32E-09	11
H4H12163P	59	83	5.66E+05	2.81E-03	4.97E-09	4
H4H12167P	38	64	6.84E+05	2.49E-03	3.64E-09	5
H4H12175P	25	4	1.12E+05	1.79E-02	1.59E-07	1
H4H12159P	51	68	5.61E+05	9.75E-04	1.74E-09	12
H4H12164P	59	64	1.77E+05	1.04E-03	5.85E-09	11
H4H12168P	34	21	6.38E+04	5.69E-04	8.90E-09	20
H4H12169P	61	75	3.29E+05	7.37E-04	2.24E-09	16
H4H11686N	39	69	2.84E+05	7.91E-04	2.78E-09	15
H4H12170P	36	61	4.24E+05	8.70E-04	2.05E-09	13
H4H12177P2	43	31	1.07E+05	5.07E-03	4.76E-08	2
H4H12183P2	31	25	5.12E+04	9.97E-04	1.95E-08	12
H4H12166P	72	54	4.91E+05	1.26E-03	2.56E-09	9
Comparator 1	41	2	NB	NB	NB	NB
Comparator 2	23	42	7.34E+05	1.07E-03	1.45E-09	11

[0244] At 25°C, all 25 anti-C5 antibodies of the invention bound to human C5 with K_D values ranging from 73 pM to 8.4 nM as shown in Table 3. At 37°C, the anti-C5 antibodies of the invention bound to human C5 with K_D values ranging from 103pM to 18.5nM as shown in Table 4. At 25°C, 25 out of the 25 anti-C5 antibodies of the invention tested bound to monkey C5-mmh with K_D values ranging from 133pM to 64 nM as shown in Table 5. At 37°C, 25 out of the 25 anti-C5 antibodies of the invention tested bound to monkey C5-mmh with K_D values ranging from 133pM to 118nM as shown in Table 6. At 25°C, 16 out of the 16 anti-C5 antibodies of the invention tested bound to human C5 R885H-mmh with K_D values ranging from 147pM to 10.9nM as shown in Table 7. At 25°C, 16 out of the 16 anti-C5 antibodies of the invention tested bound to human C5 R885C-mmh with K_D values ranging from 251pM to 190nM as

shown in Table 8. At 37°C, 16 out of the 16 anti-C5 antibodies of the invention tested bound to human C5 R885H-mmh with K_D values ranging from 1.49nM to 69.4nM as shown in Table 9. At 25°C, 16 out of the 16 anti-C5 antibodies of the invention tested bound to human C5 R885C-mmh with K_D values ranging from 1.74nM to 159nM as shown in Table 10.

Example 4: Antibody binding to C5 through different pH

[0245] Effect of pH on the rate of dissociation of recombinant human C5 bound to purified anti-C5 monoclonal antibodies was determined using a real-time surface plasmon resonance biosensor using a Biacore T200 instrument. The Biacore sensor surface was first derivatized by amine coupling with a monoclonal mouse anti-human Fc antibody (GE, # BR-1008-39) to capture anti-C5 monoclonal antibodies expressed with human IgG4 Fc. All Biacore binding studies were performed using two running buffers PBS-T, pH7.4 (0.01M Na₂HPO₄/NaH₂PO₄, 0.15M NaCl, 0.05% v/v Tween-20, adjusted to pH7.4) and PBS-T, pH6.0 (0.01M Na₂HPO₄/NaH₂PO₄, 0.15M NaCl, 0.05% v/v Tween-20, adjusted to pH6.0). Different concentrations of human C5 (EMD, Catalog # 204888) or monkey C5.mmh (prepared in PBS-T, pH7.4 running buffer (ranging from 100nM to 11.1nM, 3-fold dilutions) were injected over the anti-C5 monoclonal antibody captured surface for 3 minutes at a flow rate of 50μL/minute and their dissociation in two running buffers PBS-T, pH7.4 and PBS-T, pH6.0 was monitored for 6 minutes. All the binding kinetics experiments were performed at 25°C and 37°C. Kinetic dissociation constant (k_d) were determined by fitting the real-time sensorgrams to a 1:1 binding model using Scrubber 2.0c curve fitting software. Binding dissociative half-lives ($t_{1/2}$) were calculated from k_d as:

$$t_{1/2} \text{ (min)} = \frac{\ln(2)}{k_d}$$

[0246] Half-life ratios for human C5 binding to different anti-C5 monoclonal antibodies at 25°C and 37°C in two running buffers PBS-T, pH7.4 and PBS-T, pH6.0 are shown in Tables 11 and 12.

Table 11: Half-life ratios of selected anti-C5 antibodies for human C5 at 25°C

mAb Captured	t _{1/2} Ratio
	pH7.4 / pH6.0
H4H12169P	IC
H4H12176P2	IC
H4H12161P	IC
H4H12159P	≤ 0.3
H4H12170P	≤ 0.5
H4H12166P	4.5
H4H12183P2	IC
H4H12167P	0.6
H4H12164P	0.3
H4H12163P	1.2
H4H12175P	0.9
H4H12177P2	≤ 0.5
H4H12171P	0.6
H4H12168P	1.5
H4H12166P2	9.3
H4H12166P3	7.9
H4H12166P4	7.8
H4H12166P5	8.3
H4H12166P6	7.8
H4H12166P7	35
H4H12166P8	47
H4H12166P9	31
H4H12166P10	33
H4H11683N	2
H4H11686N	2

IC = inconclusive

Table 12: Half-life ratios of selected anti-C5 antibodies on human C5 at 37°C

mAb Captured	t½ Ratio
	pH7.4/pH6.0
H4H12169P	IC
H4H12176P2	≤ 0.4
H4H12161P	≤ 0.7
H4H12159P	≤ 0.2
H4H12170P	≤ 0.2
H4H12166P	3.8
H4H12183P2	IC
H4H12167P	0.2
H4H12164P	≤ 0.1
H4H12163P	0.8
H4H12175P	0.9
H4H12177P2	1.3
H4H12171P	3.7
H4H12168P	1
H4H12166P2	7.3
H4H12166P3	6.6
H4H12166P4	7.6
H4H12166P5	7.6
H4H12166P6	8.2
H4H12166P7	21
H4H12166P8	36
H4H12166P9	28
H4H12166P10	19
H4H11683N	1.4
H4H11686N	0.8

IC = inconclusive

[0247] Half-life ratios for monkey C5 binding to different anti-C5 monoclonal antibodies at 25°C and 37°C in two running buffers PBS-T, pH7.4 and PBS-T, pH6.0 are shown in Tables 13 and 14.

Table 13: Half-life ratios of selected anti-C5 antibodies on monkey C5 at 25°C

mAb Captured	t½ Ratio
	pH7.4/pH6.0
H4H12169P	3.4
H4H12176P2	≥ 9.1
H4H12161P	IC
H4H12159P	1.2
H4H12170P	≥ 1.7
H4H12166P	18.5
H4H12183P2	5.8
H4H12167P	9.2
H4H12164P	2.9
H4H12163P	9.7
H4H12175P	3.6
H4H12177P2	3.7
H4H12171P	2.1
H4H12168P	3.8
H4H11683N	0.34
H4H11686N	0.37

IC = inconclusive

Table 14: Half-life ratios of selected anti-C5 antibodies on monkey C5 at 37°C

mAb Captured	t½ Ratio
	pH7.4/pH6.0
H4H12169P	2
H4H12176P2	2.8
H4H12161P	10.7
H4H12159P	6.3
H4H12170P	4.7
H4H12166P	7.1
H4H12183P2	2.4
H4H12167P	4.4
H4H12164P	1.1
H4H12163P	3.3
H4H12175P	0.4
H4H12177P2	1.5
H4H12171P	4.7

H4H12168P	4
H4H11683N	0.7
H4H11686N	0.5

IC = inconclusive

[0248] As shown in Tables 11 – 14, selected anti-C5 antibodies showed pH-dependent binding, as seen by the $t_{1/2}$ ratios.

Example 5: Octet cross-competition between anti-C5 antibodies

[0249] Binding competition between anti-C5 monoclonal antibodies (mAbs) was determined using a real time, label-free bio-layer interferometry assay on an Octet RED384 biosensor (Pall ForteBio Corp.). The entire experiment was performed at 25°C in 0.01 M HEPES pH7.4, 0.15M NaCl, 0.05% v/v Surfactant Tween-20, 0.1mg/mL BSA (Octet HBS-P buffer) with the plate shaking at the speed of 1000rpm. To assess whether 2 antibodies were able to compete with one another for binding to their respective epitopes on a human C5 (hC5 purified from plasma, EMD), around 1.5 nm of anti-human C5 mAb was first captured onto anti-hFc antibody coated Octet biosensor tips (Pall ForteBio Corp., # 18-5060) by submerging the tips for 3 minutes into wells containing a 50 µg/mL solution of anti-human C5 mAb (subsequently referred to as mAb1). The antibody captured biosensor tips were then saturated with a blocking H4H isotype control mAb (subsequently referred to as blocking mAb) by dipping into wells containing 200 µg/mL solution of blocking mAb for 4 minutes. The biosensor tips were then subsequently dipped into wells containing a co-complexed solution of 50 nM hC5 and 1 µM of a second anti-human C5 mAb (subsequently referred to as mAb2), that had been preincubated for 2 hours, for 4 minutes. The biosensor tips were washed in Octet HBS-P buffer in between every step of the experiment. The real-time binding response was monitored during the course of the experiment and the binding response at the end of every step was recorded. The response of human C5 pre-complexed mAb2 binding to mAb1 was corrected for background binding, compared and competitive/non-competitive behavior of different anti-C5 monoclonal antibodies was determined.

[0250] Table 15 explicitly defines the relationships of antibodies competing in both directions, independent of the order of binding.

Table 15: Cross-competition between pairs of selected anti-C5 antibodies

First mAb (mAb1) Captured using AHC Octet Biosensors	mAb2 Antibodies Shown to Compete with mAb1
H4H12183P2	H4H12167P; H4H12166P; H4H12163P
H4H12167P	H4H12183P2; H4H12166P; H4H12163P
H4H12166P	H4H12183P2; H4H12167P; H4H12163P
H4H12163P	H4H12183P2; H4H12167P; H4H12166P
H4H12159P	H4H12169P; H4H11683N; H4H12170P
H4H12169P	H4H12159P; H4H11683N; H4H12170P
H4H11683N	H4H12159P; H4H12169P; H4H12170P
H4H12170P	H4H12159P; H4H12169P; H4H11683N
H4H12175P	H4H12177P2
H4H12177P2	H4H12175P
H4H12176P2	H4H12164P
H4H12164P	H4H12176P2
H4H12168P	none
H4H12161P	none
H4H11686N	none

Example 6: Inhibition of C5-mediated complement-dependent cytotoxicity in a B-cell bioassay

[0251] This Example describes a bioassay to test the role of C5 using an anti-CD20 antibody in the classical complement pathway. Therapeutic anti-CD20 antibodies against the B-cell specific cell-surface antigen CD20, have been shown to lead to CDC of B-cells (Glennie *et al.* 2007, Mol. Immunol. 44: 3823-3837) and CDC assay using cell lines expressing CD20 has been described previously (Flieger *et al.* 2000, Cell. Immunol. 204: 55-63). Daudi cells, a human B cell line expressing CD20, complement preserved serum or C5 depleted serum with exogenous C5 variants and an anti-CD20 antibody (antibody comprising VH/VL of “2F2” from US Patent 8,529,902) were used to assess the role of C5 activity in CDC.

[0252] For the C5 CDC bioassay, Daudi cells were seeded onto a 96-well assay plates at 10,000 cells/well in either RPMI containing 10% FBS, penicillin/streptomycin, L-glutamine, sodium pyruvate and Non-Essential Amino Acids (RPMI Complete media) or RPMI containing 1%BSA, penicillin/streptomycin and L-glutamine (RPMI/BSA). All assays testing mutated anti-hC5 antibodies, along with testing of the non-mutated

antibodies with C5 containing human serum were tested in RPMI Complete media, while assays testing the non-mutated antibodies with African Green monkey serum and human C5 variants were tested in RPMI/BSA media. To measure CDC with human or monkey serum, the anti-CD20 antibody was diluted 1:3 from 100nM to 2pM (including a control sample containing no antibody) and incubated with cells for 10 minutes at 25°C followed by addition of 1.66% serum or 1.66% of C5 depleted serum and 6.6nM C5 variant proteins. The amount of C5 protein to be added to the C5 depleted serum was based on the reported value of C5 concentration in human serum of 0.37uM (Rawal *et al* 2008, J. Biol. Chem. 283: 7853-7863). To test C5 antibody inhibition of CDC, C5 antibodies were diluted 1:3 from 100nM to 2pM (including a control sample containing no antibody) and incubated with 1.66% serum or 1.66% of C5 depleted serum and 6.6nM C5 variant proteins for 30 minutes. Ten minutes prior to addition of antibodies with serum to cells, the anti-CD20 antibody was added to cells at 1nM, 2nM, 3nM, 3.5nM, 7nM, 10nM, or 30nM. At the conclusion of the incubation with the anti-CD20 antibody, the antibody/serum mixture was added to cells. Cytotoxicity was measured after 3.5 hours of incubation at 37 °C and in 5% CO₂, followed by 15 minute incubation at 25°C, and addition of CytoTox-Glo™ reagent (Promega, # G9292). CytoTox-Glo™ is a luminescence-based reagent that measures cell killing such that increased luminescence is observed with increased cytotoxicity (measured in relative light units, RLUs). Untreated cells in control wells were lysed by treatment with digitonin immediately after addition of CytoTox-Glo™ reagent to determine maximal killing of cells. Plates were read for luminescence by a Victor X instrument (Perkin Elmer) 15 minutes following the addition of CytoTox-Glo™. Where calculated, the percentage of cytotoxicity was calculated with the RLU values by using the following equation:

$$\% \text{Cytotoxicity} = 100 \times \frac{(\text{Experimental Cell Lysis} - \text{Background Cell Lysis})}{(\text{Maximum Cell Lysis} - \text{Background Cell Lysis})}$$

[0253] In this equation “background cell lysis” is the luminescence from the cells treated with media and serum alone without any anti-CD20 antibody and the “maximum cell lysis” is the luminescence from the cells treated with digitonin. The results, expressed as % cytotoxicity or RLUs, were analyzed using nonlinear regression (4-parameter logistics) with Prism 5 software (GraphPad) to obtain EC₅₀ and IC₅₀ values. Inhibition of antibodies was calculated such that 0 – 100% inhibition is the

range of inhibition of the concentration of anti-CD20 antibody used in the assay without inhibitor to 0nM anti-CD20 antibody.

Results

[0254] A total of 25 anti-human C5 antibodies, 16 non-mutated and 9 mutated, were tested for their ability to inhibit C5 in the CDC assay using Daudi cells with an anti-CD20 antibody and either human sera (with normal hC5 or C5 variants) or African green monkey sera. Various residues in the complementary determining regions (CDRs) of H4H12166P were mutated to histidines to generate 9 mutated antibodies, H4H12166P2-H4H12166P10. Histidine mutations in the CDRs have been shown to confer pH-dependence of binding to target antigen leading to improved pharmacokinetics (Igawa *et al.* 2010, Nat. Biotechnol.28: 1203-1207).

Table 16: Non-mutated anti-hC5 antibody inhibition of CDC with 1.66% serum and anti-CD20 antibody in Daudi Cells

Serum	Human	Human	African Green monkey	C5 depleted Human and 6.6nM C5 Variant R885H	C5 depleted Human and 6.6nM C5 Variant R885C
EC50 [M] of anti-CD20 antibody (with 1.66% Serum)	1.0E-09	1.4E-09	2.4E-09	1.9E-09	2.7E-09
Constant anti-CD20 antibody (with 1.66% serum)	1nM		3nM	3.5nM	30nM
Antibody	IC50 [M]		IC50 [M] (Max % Inhibition)*	IC50 [M]	IC50 [M] (Max % Inhibition)*
H4H11683N	Not Tested	1.2E-09	4.0E-09	1.3E-09	9.0E-10
H4H11686N	Not Tested	1.5E-09	4.4E-09	1.1E-09	4.5E-10
H4H12159P	3.2E-09	Not Tested	3.4E-09	1.4E-09	1.0E-09
H4H12161P	2.4E-09	Not Tested	2.6E-09	1.8E-09	1.0E-09
H4H12163P	3.4E-09	Not Tested	3.7E-09	2.1E-09	1.1E-09
H4H12164P	2.4E-09	Not Tested	5.8E-09	1.8E-09	8.2E-10
H4H12166P	2.6E-09	Not Tested	4.5E-09	1.3E-09	4.6E-10
H4H12167P	2.5E-09	Not Tested	3.5E-09	1.9E-09	1.0E-09
H4H12168P	1.5E-09	Not Tested	2.0E-09	2.3E-09	8.6E-10
H4H12169P	1.7E-09	Not Tested	2.9E-09	1.3E-09	6.7E-10
H4H12170P	2.0E-09	Not Tested	3.7E-09	4.8E-10	4.3E-10
H4H12171P	1.9E-09	Not Tested	3.3E-09	1.6E-09	6.5E-10
H4H12175P	2.2E-09	Not Tested	5.2E-09	4.2E-09	>2.0E-08 (67%)
H4H12176P2	2.7E-09	Not Tested	3.5E-09	2.1E-09	1.3E-09
H4H12177P2	2.2E-09	Not Tested	6.1E-09	2.4E-09	1.6E-09
H4H12183P2	1.7E-09	Not Tested	1.4E-08	1.2E-09	4.5E-10
Comparator 1	2.3E-09	1.8E-09	>9.0E-08 (49%)	No inhibition	No inhibition
Control mAb 1	No Inhibition	No Inhibition	Not Tested	Not Tested	Not Tested
Control mAb 2	Not Tested	Not Tested	No Inhibition	No Inhibition	No Inhibition

*Unless otherwise noted, all inhibition is ~100%

[0255] As shown in Tables 16 and 17, all 25 anti-hC5 antibodies showed complete inhibition of CDC mediated by C5 present in 1.66% of human serum. The IC50s of the non-mutated antibodies ranged from 1.2 to 3.4nM. The IC50s of the mutated antibodies ranged from 3.0nM to 12nM. The parental, non-mutated antibody H4H12166P gave complete inhibition with IC50s of 2.6nM and 2.9nM.

Table 17: Mutated anti-hC5 antibody inhibition of CDC with 1.66% serum and anti-CD20 antibody in Daudi Cells

Serum	Human	African Green monkey	C5 depleted Human and 6.6nM C5 Variant R885H	C5 depleted Human and 6.6nM C5 Variant R885C
EC50 [M] of anti-CD20 antibody (with 1.66% Serum)	1.9E-09	2.6E-09	6.3E-09	9.5E-09
Constant anti-CD20 antibody (with 1.66% serum)	2nM	10nM	7nM	30nM
Antibody	IC50 [M]	IC50 [M] (Max % Inhibition)*	IC50 [M]	IC50 [M]
H4H12166P	2.9E-09	5.6E-09	1.3E-09	7.6E-10
H4H12166P2	3.7E-09	9.7E-09	1.7E-09	1.2E-09
H4H12166P3	7.8E-09	>3.0E-08 (64%)	2.9E-09	1.7E-09
H4H12166P4	3.5E-09	7.9E-09	1.5E-09	9.6E-10
H4H12166P5	4.9E-09	>3.0E-08 (75%)	2.1E-09	1.4E-09
H4H12166P6	3.0E-09	9.9E-09	1.3E-09	7.9E-10
H4H12166P7	7.3E-09	>6.0E-08 (61%)	4.2E-09	2.3E-09
H4H12166P8	4.1E-09	>2.0E-08 (79%)	2.1E-09	1.2E-09
H4H12166P9	3.9E-09	>1.0E-08 (85%)	1.7E-09	7.7E-10
H4H12166P10	1.2E-08	>1.0E-07 (34%)	7.0E-09	3.5E-09
Comparator 1	2.7E-09	>1.0E-07 (35%)	No Inhibition	No Inhibition
Control mAb 2	No Inhibition	No Inhibition	No Inhibition	No Inhibition

*Unless otherwise noted, all inhibition is ~100%

[0256] The sixteen non-mutated anti-hC5 antibodies showed complete inhibition of CDC mediated by African Green monkey C5 with IC50s ranging from 2.0nM to 14nM.

[0257] Four of the 9 mutated antibodies showed complete inhibition of CDC mediated by African Green monkey C5 with IC50s ranging from 7.1nM to 9.9nM. The remaining six mutated antibodies were blockers with IC50s greater than 10nM, and maximum inhibition (at 100nM antibody) ranging from 34% to 85%. The parental, non-mutated antibody H4H12166P gave complete inhibition with IC50s of 4.5nM and 5.6nM.

[0258] To test whether the anti-hC5 antibodies inhibit human C5 variants, R885H and R885C, C5-Depleted Human Serum was tested with 6.6nM of each C5 variant. All 25 anti-hC5 antibodies showed complete inhibition of CDC mediated by C5 variant R885H, with IC50s of the non-mutated antibodies ranging from 0.48nM to 4.2nM, while IC50s of the mutated antibodies ranged from 1.3nM to 7.0nM. The parental, non-mutated antibody H4H12166P gave complete inhibition with IC50s of 1.3nM and 1.3nM.

[0259] Fifteen out of 16 non-mutated anti-hC5 antibodies showed complete inhibition of CDC mediated by C5 variant R885C with IC50s ranging from 0.43nM to 1.6nM. One non-mutated antibody showed weak inhibition of CDC with maximum inhibition of 67% (at 100nM antibody) and an IC50 >20nM. All nine mutated antibodies showed complete inhibition of CDC mediated by C5 variant R885C with IC50s ranging from 0.77nM to 3.5nM. The parental, non-mutated antibody H4H12166P gave complete inhibition with an IC50s of 0.46nM and 0.76nM.

[0260] Anti-CD20 antibody showed CDC of Daudi cells with 1.66% serum with EC50s of 1.0nM, 1.4nM, and 1.9nM for human serum, 2.4nM and 2.6nM for African Green monkey serum, 1.9nM and 6.3nM for hC5 depleted serum with hC5 variant R885H, and 2.7nM and 9.5nM for hC5 depleted serum with hC5 variant R885C. Neither of the irrelevant IgG control antibodies, Control mAb1 and Control mAb2, demonstrated any inhibition of CDC.

Example 7: Inhibition of C5a activity as determined by luciferase assay

[0261] This Example describes an assay to test the activation of C5a through one of its receptors, C5aR1. C5aR1 is a G-protein coupled receptor (GPCR) and can initiate various GPCR coupled signaling pathways (Monk *et al.* 2007, Br. J. Pharmacol. 152: 429-448). A bioassay was established using HEK293 cells stably transfected with human C5aR1 (Accession No. NP_001727.1) and human Gα16 (Accession No. NP_002059.3) along with a luciferase reporter [NFAT response element (4X)-luciferase]. Gα16 is a relatively promiscuous G protein that can couple to different types of GPCRs leading to PLC-β activation and subsequent elevation of Ca⁺⁺, which in turn activates NFAT translocation and reporter gene transcription (Kostenis *et al.* 2005, Trends Pharmacol. Sci. 26: 595-602). The resulting cell line, HEK293/hGα16/hC5aR1/NFAT-luc, was isolated and maintained in 10% DMEM containing 10% FBS, NEAA, penicillin/streptomycin, 500μg/mL G418, 100μg/mL hygromycin B, and 7μg/mL blasticidin.

[0262] For the C5a luciferase bioassay, HEK293/hGα16/hC5aR1/NFAT-luc cells were seeded into 96-well assay plates at 20,000 cells/well in OPTIMEM (Invitrogen, #31985-070) supplemented with 0.5% BSA, penicillin/streptomycin and L-glutamine, and then incubated at 37°C and 5% CO₂ overnight. BSA was used instead of FBS, since serum has been shown to cleave and inactivate hC5a (Klos *et al.*, 2013, Pharmacol. Rev. 65: 500-543). The next morning, hC5a was titrated from 100nM to

2pM (including a control sample containing no hC5a) and added to cells to determine the dose response titration curve for the cell line. To test hC5a antibody inhibition of hC5a, 500pM of hC5a was added to cells. Immediately afterwards, antibodies diluted 1:3 from 100nM to 2pM (including a control sample containing no antibody) were added to cells. Cells were incubated for 5.5 hours at 37°C in the presence of 5% CO₂. The luciferase activity was detected after the incubation with OneGlo™ reagent (Promega, #E6051). OneGlo™ is a luminescence-based reagent that measures the amount of luciferase present in cells. In this assay, increased hC5a activation leads to increased luciferase production and luminescence (measured in relative light units, RLU). Measurement of luminescence was performed using a Victor X instrument (Perkin Elmer). The results were analyzed using nonlinear regression (4-parameter logistics) with Prism 5 software (GraphPad) to obtain EC₅₀ and IC₅₀ values. Inhibition of antibodies was calculated such that 0 – 100% inhibition is the range of inhibition from 500pM hC5a without inhibitor to 0nM hC5a.

[0263] Four anti-hC5 antibodies were tested for their ability to inhibit hC5a activation of its receptor, hC5aR1, by measuring the extent of inhibition of 500pM hC5a activation of HEK293/hGα16/hC5aR1/NFAT-luc cells.

Table 18: Anti-hC5 antibody inhibition of 500pM hC5a in HEK293/Gα16/hC5aR1/ NFAT-luc cells

EC ₅₀ [M] hC5a	3.9E-10
mAb PID or REGN #	Inhibition of 500pM hC5a
	IC ₅₀ [M]
H2aM11682N	4.6E-10
H2aM11684N	3.5E-11
H2aM11694N	1.4E-10
H2aM11695N	4.2E-11
Control mAb	No Inhibition

[0264] As shown in Table 18, all four antibodies of the invention, showed complete inhibition of 500pM hC5a with IC₅₀s ranging from 0.035nM to 0.46nM. An Irrelevant IgG control antibody, Control mAb3, did not demonstrate any inhibition of hC5a. hC5a activated HEK293/Gα16/hC5aR1/NFAT-luc cells with an EC₅₀ of 0.39nM.

Example 8: Hemolysis bioassay

[0265] Classical pathway hemolysis assay (CH) and alternative pathway hemolysis assay (AH) were developed to test the antibody activity.

[0266] The CH is a screening assay for the activation of the classical complement pathway, which is sensitive to the decrease, absence, and/or inactivity of any component of the pathway. The CH tests the functional capability of serum complement components of the classical pathway to lyse sheep red blood cells (SRBC) pre-coated with rabbit anti-sheep red blood cell antibody (hemolysin). When antibody-coated SRBC are incubated with test serum, the classical pathway of complement is activated and hemolysis results. If a complement component is absent, the CH level will be zero; if one or more components of the classical pathway are decreased, the CH will be decreased. (Nilsson *et al* 1984, J. Immunol. Meth. 72: 49-59). This assay is used for characterization and screening of high-affinity anti-human C5 antibodies.

Methods

(A) Classical pathway complement hemolysis assay

[0267] Desired number of sheep red blood cells (SRBCs) were washed in GVB++ buffer and re suspended at 1×10^9 cells/mL. To sensitize the SRBCs, were mixed with equal volume of the 1:50 diluted rabbit anti-sheep hemolysin (1.5mg/mL) at 37°C for 20 minutes. Sensitized SRBC cells were diluted to 2×10^8 cells/ml in GVB++ prior to using in hemolysis assay. Normal human serum or cynomolgus monkey serum was diluted to 2% or 10% in GVB++ buffer. To test the inhibition of C5 mediated hemolysis activity, test antibodies were pre-incubated for 20 minutes at 4°C, at concentrations ranging from 0.6nM to 800nM in 2% -10% normal human or 10% cynomolgus monkey serum or African green monkey serum. Round bottom 96 well plates were used to measure hemolysis activity. A total of 100ul sensitized sheep RBCs (2×10^8 cells/ml) were plated into 96-well plate followed by addition of 100ul of respective serum samples that was pre-incubated with the test antibodies. Cells were gently mixed and incubated at 37°C for 60 minutes. After the incubation time, cells were spun down by centrifugation at 1250xg at 4°C. A total of 100uL of the supernatant was transferred to a fresh 96 flat bottom plate and read at 412nm on Spectramax microplate reader. The hemolytic activity was calculated at final serum concentration of 1-5% for treatments.

[0268] Percent hemolysis was calculated as follows:

$$\%Hemolysis = 100 \times \frac{(Experimental\ Cell\ Lysis - Background\ Cell\ Lysis)}{(Maximum\ Cell\ Lysis - Background\ Cell\ Lysis)}$$

[0269] In this equation “background cell lysis” is the OD at 412nm from the cells incubated in GVB++ buffer only containing no serum. The “maximum cell lysis” is the OD at 412nm from the cells treated with water. The results, expressed as % hemolysis were analyzed using nonlinear regression (4-parameter logistics) with Prism 5 software (GraphPad) to obtain IC₅₀ values. Data represented as mean $\pm$ Standard error of mean

(B) Alternative complement assay

[0270] Desired number of rabbit red blood cells (RbRBCs) were washed in GVB-Mg²⁺/EGTA buffer and re suspended at 2x10⁸ cells/ml. Normal human or cynomolgus monkey serum was diluted to 10% in GVB-Mg²⁺/EGTA buffer. To test the inhibition of C5 mediated hemolysis activity, antibodies at concentrations ranging from 3nM to 800nM were pre-incubated for 20 minutes at 4°C in 5-10% normal human serum or cynomolgus monkey serum. Round bottom 96 well plates were used to measure hemolysis activity. A total of 100ul RbRBCs (2x10⁸ cells/ml) were plated into 96-well plate followed by addition of 100ul of 10% normal human serum or cynomolgus monkey serum or African green monkey serum that was pre-incubated with the anti-C5 antibodies. Cells were gently mixed and incubated at 37°C for 60 minutes. After incubation time, the cells were spun down by centrifugation at 1250xg at 4°C. A total of 100uL of the supernatant was transferred to a fresh 96 flat bottom plate and read at 412nm on Spectramax microplate reader. The hemolytic activity was calculated at final serum concentration of 5% serum.

[0271] Percent hemolysis was calculated as follows:

$$\%Hemolysis = 100 \times \frac{(Experimental\ Cell\ Lysis - Background\ Cell\ Lysis)}{(Maximum\ Cell\ Lysis - Background\ Cell\ Lysis)}$$

[0272] In this equation “background cell lysis” is the OD at 412nm from the cells incubated in GVB-Mg/EGTA buffer only containing no serum or without any anti-C5 antibody. The “maximum cell lysis” is the OD at 412nm from the cells treated with water. Inhibition by anti-C5 antibodies, IC₅₀ values were calculated using nonlinear regression (4-parameter logistics) with Prism 6 software (GraphPad).

Results

(A) Inhibition of human C5 hemolysis

[0273] A total of 25 anti-human C5 (hC5) antibodies, 16 non-mutated and 9 mutated, were tested for their ability to inhibit C5 from normal human serum (NHS) in the CH50

assay using sensitized sheep red blood (SRBCs) and AH50 assay using rabbit red blood cells (RRBCs).

Table 19: Anti-hC5 antibody inhibition of CP and AP activity in 1% or 5% normal human serum (NHS)

mAb PID	Human CP	Human AP	Human CP	Human AP
	IC ₅₀ [M]	IC ₅₀ [M]	% Max Inhibition	% Max Inhibition
H4H12183P2	5.88E-09	1.60E-07	99.9%	78.9%
H4H12176P2	4.58E-09	1.65E-08	94.1%	69.9%
H4H12168P	3.33E-09	2.85E-08	97.5%	66.2%
H4H11686N	3.09E-09	1.30E-08	97.4%	76.2%
H4H12167P	3.68E-09	1.55E-08	99.9%	64.8%
H4H12161P	2.56E-09	2.55E-08	93.7%	56.1%
H4H12163P	2.72E-09	2.05E-08	96.1%	66.0%
H4H12166P	2.80E-09	2.60E-08	95.0%	70.9%
H4H11683N	2.54E-09	3.40E-08	98.1%	73.2%
H4H12159P	2.50E-09	1.75E-08	97.9%	73.4%
H4H12177P2	2.34E-09	1.70E-08	97.5%	71.0%
H4H12170P	2.39E-09	1.80E-08	98.2%	81.1%
H4H12175P	2.36E-09	2.00E-08	98.0%	80.2%
H4H12171P	2.33E-09	1.55E-08	94.9%	42.0%
H4H12164P	2.10E-09	1.45E-08	95.9%	69.7%
H4H12169P	2.36E-09	2.00E-08	98.3%	44.5%
Isotype control	No Activity	No Activity	No Activity	No Activity

[0274] As shown in Table 19, sixteen anti-hC5 antibodies of this invention showed more than 94% inhibition of hemolysis in classical pathway (CP) mediated by C5 present in 1% of human serum. The IC₅₀s of antibodies ranged from 2.1 to 5.9 nM and the percent inhibition ranged from 95%-99%. All 16 anti- C5 antibodies showed more than 60% inhibition (except H4H12169P) in the alternative pathway (AP) hemolysis assay mediated by C5 present in 5% NHS. The IC₅₀s of antibodies ranged from 13 to 160 nM and the percent inhibition activity ranged from 44% to 81%.

Table 20: Anti-hC5 antibody inhibition of CP and AP activity in 5% normal human serum (NHS)

mAb PID	Human CP	Human AP	Human CP	Human AP
	IC ₅₀ [M]	IC ₅₀ [M]	% Max Inhibition	% Max Inhibition
H4H12166P	1.09E-08	2.09E-08	99.4%	86.9%
H4H12166P2	1.59E-08	4.78E-08	98.2%	81.3%
H4H12166P3	1.34E-08	6.00E-08	95.9%	78.3%
H4H12166P4	1.32E-08	3.17E-08	98.6%	77.0%
H4H12166P5	1.49E-08	6.55E-08	97.1%	77.7%
H4H12166P6	1.03E-08	2.84E-08	98.1%	82.4%
H4H12166P7	2.43E-08	1.56E-07	93.7%	83.2%
H4H12166P8	1.41E-08	7.30E-08	95.7%	73.3%
H4H12166P9	1.16E-08	5.35E-08	93.7%	72.2%
H4H12166P10	4.44E-08	No Activity	74.0%	No Activity
Isotype control	No Activity	No Activity	No Activity	No Activity

[0275] As shown in Table 20, all 9 mutated anti-hC5 antibodies showed inhibition of CP and AP hemolysis activity mediated by C5 present in 5% of human serum. In the CP hemolysis assay, the parental, non-mutated antibody H4H12166P showed more than 98% inhibition with IC₅₀ of 10.9 nM. Eight mutated anti-hC5 antibodies showed more than 90% inhibition with IC₅₀ ranging from 10.3 nM to 24.3 nM. Mutant anti-C5 antibody 12166P10 showed partial inhibition of 74%. In the AP hemolysis assay the parental, non-mutated antibody H4H12166P showed more than 85% inhibition with IC₅₀s of 20.9 nM. The mutated anti-hC5 antibodies showed inhibition range from 72-83% and the IC₅₀s antibodies ranged from 28 nM to 0.15 μM.

(B) Inhibition of monkey C5 hemolysis

[0276] A total of 25 anti-human C5 (hC5) antibodies, 16 non-mutated and 9 mutated, were tested for their ability to inhibit C5 from Cynomolgus monkey and African green monkey in the CH50 assay using sensitized sheep red blood (SRBCs) and AH50 assay using rabbit red blood cells (RRBCs).

Table 21: Anti-hC5 antibody inhibition of CP and AP activity in 5% normal African green monkey (AGM) sera

	AGM Serum CP	AGM Serum AP	AGM CP	AGM AP
mAb PID	IC ₅₀ [M]	IC ₅₀ [M]	% Max Inhibition	% Max Inhibition
H4H12183P2	No Activity	No Activity	No Activity	No Activity
H4H12176P2	3.04E-08	4.77E-08	91.0%	83.2%
H4H12168P	2.80E-08	2.25E-08	90.8%	88.2%
H4H11686N	4.82E-08	1.63E-07	49.3%	50.4%
H4H12167P	6.95E-08	6.95E-08	90.5%	53.4%
H4H12161P	3.19E-08	4.75E-08	78.9%	35.7%
H4H12163P	6.90E-08	2.16E-07	83.2%	58.5%
H4H12166P	1.30E-07	2.33E-07	81.0%	44.2%
H4H11683N	2.92E-08	4.08E-08	81.1%	88.1%
H4H12159P	2.58E-08	2.70E-08	93.4%	93.5%
H4H12177P2	1.80E-07	1.01E-07	80.6%	8.80%
H4H12170P	2.54E-08	2.69E-08	94.9%	90.9%
H4H12175P	1.18E-07	9.85E-08	84.5%	17.4%
H4H12171P	No Activity	2.33E-08	17.8%	69.70%
H4H12164P	2.47E-07	1.78E-07	85.8%	15.60%
H4H12169P	3.44E-08	9.15E-08	43.3%	45.70%

[0277] As shown in Table 21, the anti-hC5 antibodies showed different levels of inhibition of CP or AP hemolysis activity in 5% African green monkey sera. In the CP assay, two of the 16 anti-hC5 antibodies showed no inhibition of the hemolysis activity. Fourteen antibodies showed inhibition ranging from 43-94%, with IC₅₀s ranging from 25 nM to 180 nM. In the AP hemolysis assay, thirteen of the 17 antibodies showed inhibition activity ranging from 17%-93% with IC₅₀s ranging from 22.5 nM to 233nM.

Table 22: Anti-hC5 antibody inhibition of CP and AP activity in 5% normal Cynomolgus (Cyno) monkey sera

	Cyno Serum CP	Cyno Serum AP	Cyno CP	Cyno AP
mAb PID	IC ₅₀ [M]	IC ₅₀ [M]	% Max Inhibition	% Max Inhibition
H4H12183P2	1.42E-07	2.96E-08	64.6%	100.0%
H4H12171P	8.70E-09	7.20E-09	92.9%	98.8%
H4H12170P	8.20E-09	7.00E-09	99.0%	99.2%
H4H12159P	7.75E-09	7.05E-09	99.3%	99.6%
H4H12168P	1.03E-08	5.45E-09	99.0%	99.7%
H4H11683N	9.00E-09	7.15E-09	98.8%	98.9%
H4H12176P2	1.47E-08	7.70E-09	97.5%	99.3%
H4H12161P	2.79E-08	7.80E-09	100.0%	98.4%
H4H12169P	1.99E-08	7.95E-09	92.8%	96.30%
H4H11686N	1.41E-08	9.00E-09	94.5%	98.7%
H4H12163P	1.65E-08	1.02E-08	96.4%	98.5%
H4H12167P	2.13E-08	7.60E-09	100.0%	98.30%
H4H12175P	1.09E-08	8.05E-09	96.7%	98.10%
H4H12166P	2.01E-08	8.85E-09	94.2%	98.60%
H4H12177P2	1.71E-08	8.80E-09	94.90%	98.10%
H4H12164P	1.96E-08	9.10E-09	94.7%	98.70%
Isotype control	No Activity	No Activity	No Activity	No Activity

[0278] As shown in Table 22, anti-hC5 antibodies (except H4H12183P2, which showed 64% CP inhibition) showed more than 90% inhibition of CP or AP hemolysis assay in 5% of Cynomolgus monkey serum. In CP hemolysis assay, the IC₅₀s of antibodies ranged from 7.15 nM to 142 nM. In AP hemolysis assay, the IC₅₀s of antibodies ranged from 5.4 to 29.6 nM.

(C) Inhibition of variant human C5 hemolysis

[0279] Selected anti-C5 antibodies were tested for their ability to inhibit variant human C5 (see Example 3 herein) from C5-depleted human serum in the CH50 assay. In C5-depleted human serum supplemented with exogenous C5 variant R885H, H4H12166P, and Comparator 2 blocked CP hemolysis with IC₅₀ values of 6.0nM and 4.4nM, respectively, and IC₈₀ values of 7.6nM and 5.5nM, respectively. For variant R885C, H4H12166P and Comparator 2 blocked CP hemolysis in C5-depleted human serum with exogenous C5 variants with an IC₅₀ of 9.3nM and 6.8nM, respectively, and IC₈₀ values of 11nM and 8.2nM, respectively. As expected, Comparator 1 did not block the hemolytic activity of human C5 variants.

(D) Inhibition of human C5b-6 complex

[0280] Selected anti-C5 antibodies were tested for their ability to inhibit human C5b-6 complex from C5-depleted human serum in CH50 assay. H4H12166P potently blocked CP hemolysis in C5-depleted human serum supplemented with exogenous huC5b-6 complex with an IC₅₀ of 3.8nM and IC₈₀ value of 5.8nM. In contrast, Comparator 1 blocked C5b-6 complex-mediated hemolysis with lower potency, with IC₅₀ values of 5.0nM and IC₈₀ value of 46nM respectively. Comparator 1 inhibited only 70% total hemolysis at the highest concentrations tested. Comparator 2 did not block human C5b-6 complex hemolytic activity.

Example 9: Anti-C5 antibodies block generation of C5a in CP hemolysis assay

[0281] To assess whether anti-C5 antibodies inhibit the generation of C5a, supernatants from the assay for classical pathway (CP) hemolysis were analyzed for C5a levels by ELISA.

[0282] C5a, generated as the result of C5 cleavage, is a protein fragment of 74 amino acids. C5a is rapidly metabolized by serum carboxypeptidases to a more stable, less active, 73 amino acid form, C5a des-Arg, by removal of the C-terminal arginine. The quantitation of C5a des-Arg therefore provides a reliable measurement for monitoring the generation of C5a in vivo and in vitro. The MicroVue C5a ELISA kit used here detects C5a des-Arg according to information provided by the manufacturer. Preliminary experiments (data not shown) indicate that the primary 74 amino acid form of C5a is also detected. For the purpose of this Example, both forms will be collectively referred to as “C5a”.

[0283] C5a protein levels were determined in supernatants from the CP hemolysis assay using complement-preserved normal human serum (NHS) pre-incubated with H4H12166P or isotype control antibody as described in Example 8. C5a protein levels were measured using the MicroVue C5a ELISA kit according to the manufacturer's instructions. Briefly, samples were diluted and incubated on plates pre-coated with capture antibody (mouse anti-C5a specific for a neo-epitope on human C5a). Human C5a protein provided by the manufacturer was used as a standard for calibration. C5a in the supernatants was detected by HRP-conjugated detection antibody (mouse monoclonal antibody to the C5a region of C5). The chromogenic HRP-substrate, 3,3',5,5'-tetramethylbenzidine (TMB), was added to detect HRP activity. A solution of 1N hydrochloric acid was used to stop the reaction, and the optical density at 450nm

(OD450) was measured on a SpectraMax plate reader. Data were analyzed using nonlinear regression (4-parameter logistics) in GraphPad Prism. C5a concentration was expressed as ng/mL of supernatant.

[0284] In the assay using 5% NHS, H4H12166P potently blocked increases in C5a protein levels in a dose-dependent manner with an IC₅₀ of 8.5nM, while the isotype control antibody had no effect on C5a levels (Figure 1). Maximal blockade at the highest tested H4H12166P concentration (267nM) resulted in a ~10-fold decrease in C5a levels to 3.8 ng/mL (0.3nM), compared with 34 ng/mL (2.8nM) observed at the lowest tested H4H12166P concentration (1nM) in 5% serum. The C5a concentration observed for maximal blockade was close to the baseline C5a level of 2.3 ng/mL (0.2nM) in untreated 5% NHS.

Example 10: Characterization of pharmacokinetics and pharmacodynamics of anti-C5 antibodies in cynomolgus monkey

[0285] This Example describes the characterization of the pharmacokinetics (PK) and pharmacodynamics (PD) of selected anti-C5 antibodies conducted in male cynomolgus monkeys. Endogenous C5 levels were determined prior to anti-C5 antibody dosing and used to stratify animal dose groups.

[0286] Total circulating C5 levels in cynomolgus monkeys were determined using a Human Complement C5 ELISA (Abcam, cat # ab125963), which was performed according to the manufacturer's recommendations. Average concentrations of C5 protein in monkeys were determined to be 90.85 µg/mL ± 19.17 µg/mL.

[0287] For each anti-C5 antibody, 4 cynomolgus monkeys were each administered a single intravenous (IV) injection at a dose of 15 mg/kg. Blood samples were collected from each animal from pre-dose through 1680 hours (70 days), processed into serum and frozen at -80 °C until analyzed for PK and PD.

Total IgG Antibody Level Analysis by ELISA Immunoassay

[0288] Total antibody concentrations in monkey serum samples were measured using a non-validated direct ELISA. The ELISA procedure employed a microtiter plate coated with a mouse anti-human IgG1/IgG4 Fc monoclonal antibody. Different anti-C5 antibodies were added to the plate and the anti-C5 antibodies captured on the plate were detected using a biotinylated mouse anti-human IgG4 Fc monoclonal antibody,

followed by NeutrAvidin conjugated with Horseradish Peroxidase (NeutrAvidin HRP). A luminol-based substrate specific for peroxidase was then added to achieve a signal intensity that is proportional to the concentration of total captured anti-C5 antibody. The relative light unit (RLU) measurements of the calibration standards and their respective nominal concentrations were fitted using a weighted 4 Parameter Logistic equation to generate a calibration equation that described the concentration of anti-C5 antibodies and response relationship of the assay. The lower limit of quantitation (LLOQ) was 1.56ng/mL in the assay (2% monkey serum) and 78ng/mL in neat monkey serum.

Determination of PK parameters

[0289] PK parameters were determined by non-compartmental analysis (NCA) using Phoenix[®] WinNonlin[®] software (Version 6.4, Certara, L.P.) and an IV bolus dosing model.

[0290] All PK parameters were derived from the respective mean concentration values, including the observed maximum concentration in serum (C_{max}), the time of observed peak concentration, t_{max} , and the estimated half-life observed ($T_{1/2}$). For each antibody, the area under the concentration versus time curve up to the last measureable concentration (AUC_{last}) and extrapolated from time zero to infinity (AUC_{inf}) were determined using a linear trapezoidal rule with linear interpolation and uniform weighting.

PD Analysis by ex vivo Hemolysis Assay

[0291] Pharmacodynamics of selected anti-C5 antibodies was analyzed using ex vivo classical pathway and alternative pathway hemolysis assays.

[0292] Classical Pathway Hemolysis assay: Sheep red blood cells (SRBCs) were washed in GVB++ buffer (Gelatin Veronal Buffer with CaCl₂ and MgCl₂) (Boston BioProducts) and re-suspended at 1×10^9 cells/mL. To sensitize the SRBCs, a total of 1×10^9 cells/mL of SRBCs were mixed with equal volume of the 1:50 diluted rabbit anti-sheep hemolysin (1.5mg/mL) at 37°C for 20 minutes. Sensitized SRBCs were diluted to 2×10^8 cells/mL in GVB++ buffer prior to using in the hemolysis assay. Blood from cynomolgus monkeys was collected prior to dosing and at 5 minutes, 4 and 8 hours, and 1, 2, 3, 5, 7, 10, 14, 18, 21, 28, 35, 42, 49, 56, 63 and 70 days post dose for PD

analysis. Serum was prepared and frozen until further use. On day of the assay, cynomolgus serum from respective time points was diluted to 10% in GVB++ buffer. Round bottom 96 well plates were used to measure hemolysis activity. A total of 100 μ l of sensitized SRBCs (2x10⁸ cells/mL) were plated into 96-well plate at 37°C followed by addition of 100 μ l of 10% cynomolgus monkey serum from respective time points. SRBCs were gently mixed and incubated at 37°C for 10 minutes. After incubation time, the cells were centrifuged at 1250xg at 4°C. A total of 100 μ L of the supernatant was transferred to a fresh 96 flat bottom plate and read at 412nm on a Spectramax microplate reader. The hemolytic activity was calculated at final serum concentration of 5%. The percent hemolysis was calculated with the absorbance values by using the following equation:

$$\%Hemolysis = 100 \times \frac{(Experimental\ Cell\ Lysis - Background\ Cell\ Lysis)}{(Maximum\ Cell\ Lysis - Background\ Cell\ Lysis)}$$

[0293] In this equation “background cell lysis” is the OD at A412nm from the SRBCs incubated in GVB++ buffer only containing no serum. The “maximum cell lysis” is the OD at A412nm from SRBCs treated with water. The results, expressed as % hemolysis were analyzed using nonlinear regression (4-parameter logistics) with Prism 5 software (GraphPad) to obtain IC₅₀ values. Data are represented as mean $\pm$ Standard Error of Mean.

[0294] Alternative Pathway Hemolysis assay: The desired number of rabbit red blood cells (RbRBCs) were washed in GVB-Mg²⁺/EGTA buffer and re suspended at 2x10⁸ cells/mL. Blood from cynomolgus monkeys was collected prior to dosing and at 5 minutes, 4 and 8 hours, and 1, 2, 3, 5, 7, 10, 14, 18, 21, 28, 35, 42 and 49 days post dose for PD analysis. Serum was prepared and frozen until further use. Round bottom 96 well plates were used to measure hemolysis activity. A total of 100 μ l RbRBCs (2x10⁸ cells/mL) were plated into 96-well plate at 37°C followed by addition of 100 μ l of 10% cynomolgus monkey serum from the respective time points listed above. RbRBCs were gently mixed and incubated at 37°C for 60 minutes. After incubation time, the cells were centrifuged at 1250xg at 4°C. A total of 100 μ L of the supernatant was transferred to a fresh 96 flat bottom plate which was read at 412nm on a Spectramax microplate reader. The hemolytic activity was calculated for final serum concentration of 5% and expressed as percentage of total hemolysis of RBCs by water. The percent of hemolysis was calculated as described above.

Results

[0295] Selected anti-C5 antibodies (listed in Table 1) were tested in initial experiments for prolonged pharmacokinetic profiles in cynomolgus monkeys and C5-humanized mice (described in Example 10). H4H12166P and H4H12161P were selected as having high affinity coupled with prolonged PK and used in subsequent experiments herein with Comparator 1 and Comparator 2.

[0296] Cynomolgus monkeys were administered a single 15 mg/kg IV bolus dose of H4H12166P, H4H12161P, or Comparator 2. Serum concentrations of total antibody and percent classical pathway (CP) hemolysis activity were determined at 19 time points during a 70-day in-life period. Alternative pathway (AP) hemolysis was determined at 17 time points during a 50-day in-life period. Table 23 summarizes the mean antibody concentrations for all 3 antibodies. Mean total antibody concentrations versus time profiles are shown in Figure 2. Mean PK parameters are described in Table 24.

Table 23: Mean Concentrations of Total IgG in Serum Following a Single 15 mg/kg Intravenous Injection of Selected Anti-C5 Antibodies to Male Cynomolgus Monkeys

Time (hours post-dose)	#	Serum concentration of Ab (µg/mL) Mean ±SD		
		H4H12166P	H4H12161P	Comparator 2
0	4	BLQ	BLQ	BLQ
0.083	4	445 ±30	456 ±26.2	459 ±55.2
4	4	328 ±27	360 ±28.2	363 ±43.8
8	4	353 ±29.9	316 ±21.5	357 ±16.1
24	4	282 ±43.6	276 ±32.4	248 ±19.6
48	4	225 ±15.2	221 ±21.5	212 ±19.3
72	4	180 ±15.0	181 ±17.2	196 ±36.2
120	4	194 ±20.9	162 ±10.7	179 ±23.3
168	4	171 ±29.9	132 ±17.0	157 ±18.4
240	4	157 ±12.7	96.1 ±17.3	114 ±13.0
336	4	120 ±10.2	49.3 ±18.7	67.9 ±25.8
432	4	105 ±13.9	24.6 ±11.8	42.6 ±15.9
504	4	92.2 ±10.6	13.8 ±9.95	28.6 ±13.1
672	4	75.1 ±15.8	6.16 ±2.40	10.9 ±6.25
840	3	59.6 ±4.79	2.44 ±0.85	4.45 ±2.63
1008	3	43.3 ±2.89	1.16 ±0.52	2.17 ±1.58
1176	3	30.6 ±1.42	0.57 ±0.25	1.29 ±1.16
1344	3	25.9 ±3.74	0.315 ±0.16	0.492 ±0.49
1512	3	18.2 ±2.41	0.17 ±0.08	0.270 ±0.27
1680	3	11.5 ±1.51	0.079 ±0.07	0.123 ±0.15

Time = Time in hours post single-dose injection;
SD = Standard deviation; BLQ = Below Limit of Quantitation

[0297] Following IV bolus administration, the total IgG concentration-time profiles of H4H12166P, H4H12161P, and Comparator 2 were characterized by an initial brief distribution phase followed by single elimination phases throughout the in-life period. Peak H4H12166P, H4H12161P, and Comparator 2 concentrations were highly comparable, as corresponding $C_{\max}$ /Dose values between all the antibodies were within 1.1-fold (29.7, 30.4, and 30.6 [($\mu\text{g/mL}$)/(mg/kg)], respectively) (Table 24).

Table 24: Mean Pharmacokinetic Parameters of Total IgG Concentrations in Serum Following a Single 15 mg/kg Intravenous Injection of Selected Anti-C5 Antibodies to Male Cynomolgus Monkeys

Parameter	H4H12166P		H4H12161P		Comparator 2	
	15 mg/kg IV (n = 4)					
	Mean	SD	Mean	SD	Mean	SD
C _{max} (µg/mL)	445	30.0	456	26.2	459	55.2
C _{max} /Dose (µg/mL)/(mg/kg)	29.7	2.00	30.4	1.75	30.6	3.68
C ₀ (µg/mL)	448	30.5	458	26.6	461	55.6
t _{max} (hours)	0.083	0	0.083	0	0.083	0
AUC _{last day} •(µg/mL)	5080	1040	2350	357	2810	470
AUC _{last} /Dose day• (µg/mL)/(mg/kg)	339	69.3	157	23.8	187	31.3
AUC _{inf} day•(µg/mL)	5550	671	2350	356	2810	470
AUC _{inf} /Dose day• (µg/mL)/(mg/kg)	370	44.7	157	23.7	188	31.4
CL (mL/h/kg)	0.114	0.0143	0.270	0.0411	0.228	0.0425
V _{ss} (mL/kg)	60.4	4.85	44.0	4.34	45.3	3.06
t _{1/2} (day)	15.6	1.43	5.50	2.45	5.91	1.13

IV = Intravenous; n = Number of animals; $C_{\max}$ = Peak concentration; C_0 = Initial concentration determined by extrapolation; $t_{\max}$ = Time to $C_{\max}$; AUC = Area under the concentration-time curve; AUC_{last} = AUC computed from time zero to the time of the last positive concentration; AUC_{inf} = AUC from time zero extrapolated to infinity; CL = Total body clearance; V_{ss} = Volume of distribution at steady state; $t_{1/2}$ = Half-life; SD = Standard Deviation.

Note: $t_{\max}$ is expressed in nominal hours

[0298] Assessment of concentration-time profiles revealed that H4H12166P demonstrated the slowest elimination with terminal antibody concentrations ≥ 10 $\mu\text{g/mL}$ through study day 71. Kinetics of H4H12161P and of Comparator 2 were similar; both demonstrated more rapid elimination than H4H12166P, with mAb concentrations ≥ 10 $\mu\text{g/mL}$ through day 22 and 29, respectively.

[0299] Consequently, dose-normalized exposures ($\text{AUC}_{\text{last}}/\text{Dose}$) indicated that H4H12166P had the highest exposure at 339 day*($\mu\text{g/mL}$)/(mg/kg), while H4H12161P

and Comparator 2 had approximately 2-fold lower exposure, 157 and 187 day*($\mu\text{g/mL}$)/(mg/kg), respectively, than that of H4H12166P.

[0300] Antibody half-life ($t_{1/2}$) calculated during the elimination phase ranged from 5.5 to 15.6 days across the dose groups and also correlated with exposure, as H4H12166P had the correspondingly highest $t_{1/2}$ of 15.6 days, while H4H12161P and Comparator 2 had $t_{1/2}$ values of 5.5 and 5.9 days, respectively.

[0301] The pharmacologic effects of the anti-C5 antibodies from cynomolgus monkey serum samples were determined ex vivo by complement classical pathway (CP) hemolysis of sensitized sheep red blood cells (SRBCs) and alternative pathway (AP) hemolysis of rabbit red blood cells (RbRBCs). The inhibition of hemolytic activity was calculated for a final serum concentration of 5% and expressed as percentage of total hemolysis of RBCs by water. Table 25 summarizes ex vivo activity of the 3 antibodies as determined by mean percent hemolysis.

Table 25: Ex Vivo Classical and Alternative Pathway Percent Hemolysis Activity of Selected anti-C5 Antibodies

Time (hours post-dose)	#	Classical Pathway % Hemolysis in cynomolgus serum, 10 min, Mean $\pm$ SEM			Alternative Pathway % Hemolysis in cynomolgus serum, 60 min, Mean $\pm$ SEM		
		H4H12166P	H4H12161P	Comparator 2	H4H12166P	H4H12161P	Comparator 2
0	4	91.34 $\pm$ 7.6	Not tested	84.36 $\pm$ 20.28	73.44 $\pm$ 17.26	64.90 $\pm$ 19.51	55.77 $\pm$ 10.82
0.083	4	3.5 $\pm$ 1.4	Not tested	6.6 $\pm$ 6.5	5.53 $\pm$ 1.98	5.90 $\pm$ 3.92	3.83 $\pm$ 3.93
4	4	2.35 $\pm$ 1.06	Not tested	3.16 $\pm$ 2.2	7.43 $\pm$ 2.54	6.53 $\pm$ 2.7	5.30 $\pm$ 2.80
8	4	1.55 $\pm$ 0.21	Not tested	1.25 $\pm$ 0.21	3.53 $\pm$ 0.91	4.70 $\pm$ 2.77	1.98 $\pm$ 0.83
24	4	7.7 $\pm$ 6.08	Not tested	4.55 $\pm$ 2.05	13.40 $\pm$ 2.77	4.68 $\pm$ 1.89	4.65 $\pm$ 2.35
48	4	2.85 $\pm$ 2.19	Not tested	2.6 $\pm$ 0.7	5.53 $\pm$ 2.40	7.68 $\pm$ 5.22	2.28 $\pm$ 0.67
72	4	0.9 $\pm$ 0.42	Not tested	1.3 $\pm$ 0.28	7.95 $\pm$ 3.36	5.95 $\pm$ 2.23	1.45 $\pm$ 0.33
120	4	1.75 $\pm$ 0.07	Not tested	1.3 $\pm$ 0.14	16.38 $\pm$ 6.91	7.60 $\pm$ 1.94	1.68 $\pm$ 0.22
168	4	1.6 $\pm$ 1.13	Not tested	1.4 $\pm$ 0.56	21.28 $\pm$ 8.24	10.75 $\pm$ 2.27	2.15 $\pm$ 0.19
240	4	1 $\pm$ 0.14	Not tested	3.7 $\pm$ 2.83	19.18 $\pm$ 10.20	13.53 $\pm$ 7.17	14.20 $\pm$ 16.73
336	4	2.55 $\pm$ 2.05	Not tested	37.85 $\pm$ 5.3	21.10 $\pm$ 7.55	50.58 $\pm$ 12.91	65.60 $\pm$ 26.04
432	4	1.35 $\pm$ 0.91	Not tested	105.25 $\pm$ 3.3	15.20 $\pm$ 10.86	59.75 $\pm$ 12.65	54.55 $\pm$ 19.11
504	4	3.55 $\pm$ 2.05	Not tested	107.1 $\pm$ 4.38	33.15 $\pm$ 8.80	88.55 $\pm$ 24.63	85.63 $\pm$ 27.48
672	4	2.2 $\pm$ 0.56	Not tested	88.9 $\pm$ 23.05	75.25 $\pm$ 18.30	88.55 $\pm$ 8.53	91.58 $\pm$ 18.55
840	3	3.075 $\pm$ 2.70	Not tested	105.37 $\pm$ 53.4	46.65 $\pm$ 5.30	92.33 $\pm$ 5.16	91.85 $\pm$ 2.33
1008	3	15.5 $\pm$ 26.6	Not tested	108.85 $\pm$ 2.35	58.60 $\pm$ 9.48	92.45 $\pm$ 6.27	92.30 $\pm$ 2.69
1176	3	58.33 $\pm$ 39.55	Not tested	113.85 $\pm$ 2.62	72.95 $\pm$ 5.87	104.90 $\pm$ 3.5	101.90 $\pm$ 0.42
1344	3	71.55 $\pm$ 43.02	Not tested	110.3 $\pm$ 1.98	Not tested	Not tested	Not tested
1512	3	91.375 $\pm$ 29.7	Not tested	110.6 $\pm$ 0.85	Not tested	Not tested	Not tested
1680	3	112.22 $\pm$ 4.06	Not tested	112.15 $\pm$ 0.5	Not tested	Not tested	Not tested

Time = Time in hours post single-dose injection; SEM = Standard error of mean; BLQ = Below Limit of Quantitation; NC = Not calculated

[0302] As shown in Table 25 and Figure 2, PD effects were measured by complement CP (10 minute incubation) to Day 70. H4H12166P blocked more than 95% of CP hemolytic activity until day 35. Activity returned to pre-study maximum hemolysis

levels by day 70. Comparator 2 blocked about 95% of CP hemolytic activity through day 10, and activity rapidly returned to pre-study maximum hemolysis levels by day 18.

[0303] PD effects were also measured by complement AP pathway (60 minute incubation) hemolysis assays to day 49. As shown in Table 25 and Figure 3, H4H12166P blocked 80% of the total AP hemolytic activity until day 18 and activity returned to pre-study maximum hemolysis level at day 50. H4H1216P and Comparator 2 blocked 90% of AP hemolytic activity through day 7, and activity returned to pre-study maximum hemolysis levels by day 21.

Example 11: Characterization of PK/PD of anti-C5 antibodies in C5-humanized mice

[0304] In this set of experiments, the pharmacokinetics and pharmacodynamics of selected anti-C5 antibodies were assessed in mice humanized to express human C5 protein using Velocigene® technology (Valenzuela *et al* 2003, Nat. Biotechnol. 21: 652-659). Humanized mice were engineered to replace exon 2 through exon 41 of murine C5 gene with exons 2 – 42 of human C5 gene (disclosed in US Patent Application Publication 2015/0313194, herein incorporated in its entirety).

[0305] Total circulating human C5 levels were determined using a Human Complement C5 ELISA (Abcam, cat # ab125963), which was performed according to manufacturer's recommendations.

Determination of Total Drug Level in Serum by ELISA

[0306] Circulating anti-C5 antibody concentrations, both C5-bound and -unbound, were determined by total human antibody analysis using ELISA. Briefly, a goat anti-human IgG polyclonal antibody at 1 µg/mL in PBS was immobilized on 96-well plates overnight; plates were washed to remove unbound IgG and then blocked with 5% BSA. Serial dilutions of anti-C5 antibody containing serum samples (6 points) and the reference standards (12 points) of the respective antibodies were transferred to the anti-human IgG coated plates and incubated for one hour. The plate-bound anti-C5 antibodies were then detected using a goat anti-human IgG polyclonal antibody conjugated with horseradish peroxidase. Plates were developed with TMB substrate according to the manufacturer's recommended protocol and signals of optical density (OD) at 450 nm were recorded using a Perkin Elmer Victor X4 Multimode Plate

Reader. Anti-C5 antibody concentrations in serum were calculated based on the reference standard calibration curve generated using GraphPad Prism software.

Determination of PK parameters

[0307] PK parameters were determined by non-compartmental analysis (NCA) using Phoenix®WinNonlin® software (Version 6.3, Certara, L.P.) and an extravascular dosing model. Using the respective mean concentration values for each antibody, all PK parameters, including estimated half-life observed ($t_{1/2}$), and area under the concentration versus time curve up to the last measureable concentration (AUC_{last}) were determined using a linear trapezoidal rule with linear interpolation and uniform weighting.

PD Analysis by Hemolysis Assay

[0308] Pharmacodynamics of selected anti-C5 antibodies was determined using a classical pathway complement hemolysis assay. Sheep red blood cells (SRBCs) (Sheep blood in Alsevers solution) were washed in GVB++ buffer (Gelatin Veronal Buffer with $CaCl_2$ and $MgCl_2$) (Boston BioProducts) and re suspended at 1×10^9 cells/mL. To sensitize, 1×10^9 /mL of SRBCs were mixed with equal volume of the 1:50 diluted rabbit anti-sheep hemolysin (1.5mg/mL) at 37°C for 20 minutes. Sensitized SRBCs were diluted to 2×10^8 cells/mL in GVB++ prior to use in the hemolysis assay. Serum samples from pre-dosed animals or humanized C5 mice dosed with anti-C5 antibodies collected on days 10, 20, 30, 40 and 50 post-dose were diluted to 20% in GVB++ buffer. A total of 100µl sensitized SRBCs (2×10^8 cells/mL) were plated into 96-well round bottom plates at 37°C followed by addition of 100µl of 20% serum that was supplemented with 160-180µg/mL human complement 3 (huC3) protein. Cells were gently mixed and incubated at 37°C for 1 hour. After incubation, the cells were centrifuged at 1250xg at 4°C. A total of 100µL of supernatant was transferred to a fresh 96 flat bottom plate and read at A412nm on a Spectramax microplate reader. The percent hemolysis was calculated with the absorbance values by using the following equation:

$$\%Hemolysis = 100 \times \frac{(Experimental\ Cell\ Lysis - Background\ Cell\ Lysis)}{(Maximum\ Cell\ Lysis - Background\ Cell\ Lysis)}$$

[0309] In this equation “background cell lysis” is the OD at A412nm from SRBCs incubated in GVB++ buffer only containing no serum. The “maximum cell lysis” is the

OD at A412nm from SRBCs treated with water. The results, expressed as % hemolysis, were analyzed using nonlinear regression (4-parameter logistics) with Prism 6 software (GraphPad) to obtain IC₅₀ values. Data represented as Mean ± (Standard Error of Mean).

Experiment 1

[0310] In this experiment, the pharmacokinetics and pharmacodynamics of exemplary antibody H4H12166P were assessed in comparison with Comparator 1 and Comparator 2 in humanized C5 mice. Total circulating human C5 levels were determined using a Human Complement C5 ELISA (Abcam, cat # ab125963), which was performed according to manufacturer's recommendations. Average concentrations of human C5 in the mice were determined to be 39.73µg/mL ± 17.82µg/mL. There was a difference between male (55.4 ± 1.7 µg/ml, n=47) and female (24.7 ± 0.6 µg/ml, n=49) mice.

[0311] Prior to antibody dosing, male and female humanized C5 mice were stratified according to human C5 levels that averaged 40µg/mL. For each anti-C5 antibody, cohorts of twenty-two mice received a single 15mg/kg dose of H4H12166P, Comparator 1 or Comparator 2 by subcutaneous (s.c.) injection. All mice were bled predose and at one day post-injection for PK analysis. In addition, at 10, 20, 30, 40 and 50 days post injection, groups of 4 or 5 mice from each cohort were euthanized and terminal bleeds were collected for PK and PD analysis. Day 1 serum samples were the mean of the entire cohort of 22 mice. Blood was processed into serum and frozen at -80 °C until analyzed.

[0312] Total antibody concentrations were determined at 7 time points and percent hemolysis activity was determined at 6 time points over the 50-day in-life period. Total anti-C5 antibody concentrations are summarized in Table 26. The mean total antibody concentrations versus time profile are shown in Figure 4. Mean PK parameters are described in Table 27.

Table 26: Mean Concentrations of Total IgG in Serum Following a Single 15 mg/kg Subcutaneous Injection of anti-C5 antibodies in Humanized C5 mice

Time (Day)	#	Serum concentration of Ab ($\mu\text{g/mL}$)		
		Mean $\pm$ SD		
		H4H12166P	Comparator 1	Comparator 2
1	22	178 $\pm$ 22.7	229 $\pm$ 40.7	164 $\pm$ 24.1
10	4	83.7 $\pm$ 22.2	102 $\pm$ 22.9	44 $\pm$ 24.1
20	5	57.1 $\pm$ 26.8	29 $\pm$ 31.3	11.4 $\pm$ 10.3
30	5	38.1 $\pm$ 7.6	30.1 $\pm$ 34.2	3.6 $\pm$ 3.2
40	4	11.9 $\pm$ 5.0	0.4 $\pm$ 0.4	0.5 $\pm$ 0.4
50	4*	9.3 $\pm$ 12.2	0.3 $\pm$ 0.3	0.3 $\pm$ 0.2

Time = Time in hours post single-dose injection; Day = Day of study; SD = Standard deviation; SEM = Standard error of mean; ND = Not detected; NS = No sample. *For Comparator 2, day 50, n= three due to the inability of one sample to be analyzed due to technical issues.

Table 27: PK parameters

Parameter	Units	H4H12166P	Comparator 1	Comparator 2
Day 1 mAb concentration	$\mu\text{g/mL}$	178	229	164
AUC _{last}	day $\cdot$ $\mu\text{g/mL}$	2801	2708	1418
$t_{1/2}$	d	11.3	4.7	7.6

C_{max} = Peak concentration; AUC = Area under the concentration-time curve; AUC_{last} = AUC computed from time zero to the time of the last positive concentration; $T_{1/2}$ = Estimated half-life observed

[0313] Mean concentration versus time profiles at day 1 show that the three antibodies, H4H12166P, Comparator 1 and Comparator 2 had comparable serum concentrations of 178, 229 and 164 $\mu\text{g/mL}$, respectively. Comparator 1 had a similar elimination profile to H4H12166P up to day 30, but at days 40 and 50 exhibited a rapid increase in clearance versus H4H12166P. At day 50, H4H12166P had an average antibody serum concentration of approximately 9 $\mu\text{g/mL}$, whereas Comparator 1 and Comparator 2 both had a 30-fold lower average antibody serum concentration of 0.3 $\mu\text{g/mL}$. Comparator 2 exhibited the lowest exposure of the three antibodies tested, with an approximately 2-fold lower AUC_{last} (1408 day $\cdot$ $\mu\text{g/mL}$) as compared to H4H12166P (2801 day $\cdot$ $\mu\text{g/mL}$) and Comparator 1 (2708 day $\cdot$ $\mu\text{g/mL}$).

[0314] The pharmacologic effects of anti-C5 antibodies H4H12166P, Comparator 1 and Comparator 2 from humanized C5 mouse serum samples supplemented with

human C3 were measured out to day 50 and were determined ex vivo by complement classical pathway (CP) hemolysis of sensitized SRBC. Mean percent hemolysis for each anti-C5 antibody is summarized in Table 28 and the mean percent hemolysis versus time profile is shown in Figure 5.

Table 28: Ex Vivo Classical Pathway Percent Hemolysis Activity of anti-human C5 antibodies

Time (Day)	#	Classical pathway % hemolysis in 10% mouse serum, 60 min, Mean±SEM		
		H4H12166P	Comparator 1	Comparator 2
1	22	NS	NS	NS
10	4	12.6±7.79	10.39±2.88	12.06±9.12
20	5	18.8±8.1	21.59±17.53	65.08±52.87
30	5	13.76±10.9	78.98±40.3	91.67±16.74
40	4	41.71±40.7	101.09±4.01	68.99±42.47
50	4*	62.2±56.6	88.99±17.51	105.14±4.07

Time = Time in hours post single-dose injection; Day = Day of study; SEM = Standard error of mean; ND = Not detected; NS = No sample. *For Comparator 2, day 50, n= three due to the inability of one sample to be analyzed due to technical issues

[0315] H4H12166P, Comparator 1 and Comparator 2 inhibited the terminal complement hemolytic activity that appeared to correlate with antibody exposures. H4H12166P blocked more than 85% of hemolytic activity until day 30 with activity returning to predose baseline levels by day 50. Comparator 1 and Comparator 2 blocked about 80% hemolytic activity until day 20 and day 10, respectively, with activity returning to baseline levels by day 30 for both.

Experiment 2

[0316] In this experiment, the pharmacokinetics and pharmacodynamics of anti-C5 antibodies H4H12166P, H4H12161P, Comparator 1, and an isotype control was assessed in humanized C5 mice (mice homozygous for human C5 expression). Total circulating C5 levels were determined using a Human Complement C5 ELISA (Abcam, cat # ab125963), which was performed according to the manufacturer's recommendations. Average concentrations of human C5 in the mice were determined to be 48.98µg/mL ± 15.1 µg/mL.

[0317] Prior to antibody dosing, humanized male and female C5 mice were stratified according to human C5 levels that averaged 50µg/mL. For each anti-C5 mAb, cohorts of five mice received a single 15 mg/kg subcutaneous (s.c.) injection of H4H12166P,

H4H12161P, Comparator 1 or an isotype control. All mice were bled predose, 6 hours, 1, 2, 3, 4, 7, 10, 13, 21, 30 and 45 days post injection for PK analysis. In addition, on day 59, all mice from each cohort were euthanized and terminal bleeds were collected for PK and PD analysis. Blood was processed into serum and frozen at -80 °C until analyzed.

[0318] Total antibody concentrations were determined at 12 time points and percent hemolysis activity was determined at 1 time point during a 59-day in-life period. Total serum antibody concentrations for each anti-C5 antibody are summarized in Table 29. Mean total antibody concentration versus time profiles are shown in Figure 6. Mean PK parameters are described in Table 30.

Table 29: Mean Concentrations of Total IgG in Serum Following a Single 15 mg/kg Subcutaneous Injection of selected anti-C5 antibodies in Humanized C5 mice

Time (Day)	Serum concentration of Ab (µg/mL) Mean±SD			
	H4H12166P	H4H12161P	Comparator 1	Isotype Control
0	ND	ND	ND	ND
0.25	31.2±4.2	43.5±16.3	59.2±24.1	61.5±29.4
1	149.9±16.1	193.8±24.1	179.0±9.8	218.1±17
2	160.8±20	221±26.5	166.6±22.3	188.8±25.8
3	166.2±12.4	210±31.2	159.2±33.2	177.9±26.2
7	158.6±8.5	162.5±34.8	136.1±38.1	184.9±33.9
10	123.5±28.7	133.2±20.2	107.2±45.7	159.5±28.8
13	93.7±23.6	97.2±24.6	70.6±38	117.2±24.1
21	60.4±14.9	42.4±30.3	29.5±20.6	80.0±17.5
30	37.8±10.8	15.3±19.7	4.2±3.5	42.1±6.7
45	20.7±5.2	3.5±5.2	0.4±0.3	16.5±13.9
59	4.1±1.9	0.6±1.0	0.08±0.04	4.6±4.5

Time = Time in hours post single-dose injection; Day = Day of study; SD = Standard deviation; SEM = Standard error of mean; ND = Not detected; NS = No sample.

Table 30: PK parameters

Parameter	Units	Test Antibody (mean $\pm$ SD)			
		H4H12166P	H4H12161P	Comparator 1	Isotype control
$C_{\max}$	$\mu\text{g/mL}$	178 ± 10	225 ± 22	183 ± 18	221 ± 19
AUC_{last}	$\text{d} \cdot \mu\text{g/mL}$	3490 ± 590	3040 ± 900	2240 ± 780	4080 ± 480
$t_{1/2}$	D	11 ± 1	5.8 ± 2	4.2 ± 1	9.9 ± 4

$C_{\max}$ = Peak concentration; AUC = Area under the concentration-time curve; AUC_{last} = AUC computed from time zero to the time of the last positive concentration; $T_{1/2}$ = Estimated half-life observed.

[0319] Mean concentration versus time profiles show that H4H12166P, H4H12161P, Comparator 1 and isotype control reached a maximum serum concentration ($C_{\max}$) between days 1 to 3, with comparable $C_{\max}$ values within 1.3-fold (178, 225, 183 and 221) $\mu\text{g/mL}$, respectively. H4H12166P and isotype control had similar elimination profiles, with remaining drug levels of approximately $4\mu\text{g/mL}$ at day 59. H4H12161P exhibited faster clearance than H4H12166P and isotype control but cleared more slowly than Comparator 1. At day 59, H4H12161P had mean serum drug level of $0.6\mu\text{g/mL}$ while Comparator 1 had an almost undetectable drug level of $0.08\mu\text{g/mL}$.

[0320] The isotype control, H4H12166P and H4H12161P exhibited comparable exposure (AUC_{last}) values within 1.3-fold (4080, 3490 and 3040 $\text{day} \cdot \mu\text{g/mL}$, respectively) whereas Comparator 1 exhibited a 1.6-fold lower exposure (2240 $\text{day} \cdot \mu\text{g/mL}$) compared to H4H12166P.

Example 12: LC-MRM-MS-based assay to determine the concentration of total human C5

[0321] In this Example, serum concentrations of total human C5 were determined using a liquid chromatography coupled to multiple reaction monitoring mass spectrometry (LC-MRM-MS) method in a pharmacokinetics/pharmacodynamics study of anti-C5 antibody H4H12166P.

[0322] The serum concentrations of total human C5 were determined by measuring the concentration of a 10-amino acid peptide contained in the C5 sequence LQGTLPEAR (aa 1129-1138 of SEQ ID NO: 359) as a proxy for C5. Theoretically, this method could also detect the C5 split product, C5b. However, due to the instability

of free C5b, concentrations C5b in serum are generally low with the majority of C5b being bound to cell surfaces in the form of MAC complexes (Cooper & Muller-Eberhard 1970, J. Exp. Med. 132: 775-93; Hadders et al 2012, Cell Rep. 1: 200-7). Therefore, the processed serum samples analyzed here are likely to contain only negligible amounts of C5b product, if any.

Methods

[0323] For the PK/PD study, mice received a single 15mg/kg dose of H4H12166P by subcutaneous (s.c.) injection. All mice were bled predose and at one day post-injection for PK analysis. In addition, at 10, 20, 30, 40, 50 and 60 days post injection, mice were euthanized and terminal bleeds were collected for PK and PD analysis.

[0324] Human C5 was used as a reference standard for calibration; and a human C5 peptide produced with a C-terminal stable isotope-labeled arginine residue was used as the internal standard (LQGTLPVEAR-¹³C₆¹⁵N₄). Reference standard was used at concentrations ranging from 3.9 to 250 µg/mL (1:2 serial dilutions) in serum from in house-generated C5 knock-out mice, in which the mouse C5 gene was deleted (C5^{-/-}). Serum from C5^{-/-} mice was also used as a negative control (blank). Calibration standards, blanks, and study serum samples (10 µL each) were dried and then were denatured in 100 µL of 8M urea/20mM Tris(2-carboxyethyl)phosphine (TCEP) buffer at 37°C for 1 hour. Next, 10 µL of 25nM internal standard was added to all samples. Samples were alkylated with 10mM of 2-iodoacetamide at room temperature for 30 minutes and were diluted using 50mM ammonium bicarbonate to a final volume of 500 µL. The samples were then digested by trypsin (1:20 w/w) overnight at 37°C. The tryptic peptide LQGTLPVEAR derived from C5 was detected and quantified by LC-MRM-MS using a Waters Xevo TQ-S with ACQUITY UPLC system. Each processed sample (10 µL) was injected onto a pre-equilibrated ACQUITY UPLC BEH C18 Column. The flow rate was 0.6 mL/min (Mobile Phase A: water:formic acid/100:0.1 [V:V] and Mobile Phase B: acetonitrile:formic acid/100:0.1 [V:V]). Retention time and peak area were determined using Masslynx Analyst Data software (Waters). Concentrations of C5 analyte were calculated from the calibration curve which was constructed by plotting the peak area ratio of C5 reference standard (unlabeled C5 peptide LQGTLPVEAR-¹²C₆¹⁴N₄ generated by tryptic digest of hC5) to internal standard (stable isotope-labeled C5 peptide) versus the nominal concentration of C5 reference standard. Concentrations were calculated using linear regression. The lowest

concentration of C5 reference standard (3.9 µg/mL) was within the dynamic range of the assay and was defined as the assay's LLOQ.

Results

[0325] Concentrations of total human C5 in serum were evaluated for samples collected and via tail bleed in advance of dosing (predose) and via terminal bleed on days 10, 30 and 35, from the corresponding animals. Total hC5 concentrations following H4H12166P dosing were similar (within ~1 to 0.9-fold) to predose levels on days 10, 30, and 35 post dosing. The observed minor differences were not statistically significant as assessed by Mann–Whitney test using GraphPad Prism software. Analysis of the C5/ H4H12166P molar ratio demonstrated that H4H12166P remained in molar excess of C5 through day 35 post dosing (Table 31).

Table 31: Summary of PD characteristics of H4H12166P

Day Post dose	% CP Hemolysis Mean±SD	% Inhibition	C5 (µg/mL)			H4H12166P (µg/mL) mean±SD	Molar ratio terminal C5: H4H12166P
			Predose	Terminal	Fold Change		
0	77.2	0	n/d			n/a	n/a
10	5.2	93	34.2	30.0	1.0	78.8	0.3
30	7.4	90	31.9	28.4	0.9	30.4	0.8
35	6.0	92	36.1	32.7	1.0	29.6	0.9
40	37.1	52	n/d			20.9	n/d
50	All animals in group excluded due to MAHA titers > 1000						
60	73.57	5	n/d			5.9	n/d

^aPercentage of inhibition of CP hemolytic activity was calculated from mean % CP hemolysis values on the indicated day post dosing relative to the mean % CP hemolysis value on day 0. ^bFold Change = terminal (indicated day post dosing) C5: predose C5. SD = standard deviation; MAHA = mouse anti-human antibody; n/d = not determined. Animals with MAHA-impacted data were completely excluded from calculations (2x day 30, 1x day 35, 2x day 40, and all 4 mice on day 50).

Example 13: Epitope mapping of H4H12166P binding to C5 by Hydrogen/Deuterium Exchange

[0326] H/D exchange epitope mapping with mass spectrometry was carried out to determine the amino acid residues of hC5 [(amino acids M1-C1676 of SEQ ID No: 359) with which H4H12166P interacts. A general description of the H/D exchange method is set forth in e.g., Ehring (1999) *Analytical Biochemistry* 267(2):252-259; and Engen and Smith (2001) *Anal. Chem.* 73:256A-265A.

[0327] HDX-MS experiments were performed on an integrated Waters HDX/MS platform, consisting of a Leaptac HDX PAL system for the deuterium labeling, a Waters Acquity M-Class (Auxiliary solvent manager) for the sample digestion and loading, a Waters Acquity M-Class (μ Binary solvent manager) for the analytical column gradient, and Synapt G2-Si mass spectrometer for peptic peptide mass measurement.

[0328] The labeling solution was prepared in 10 mM PBS buffer in D₂O at pD 7.0 (equivalent to pH 6.6). For deuterium labeling, 3.8 μ L of C5 (6 pmol/ μ L) or C5 premixed with the antibody in 1:1 molar ratio was incubated with 56.2 μ L D₂O labeling solution for various time-points (*e.g.*, undeuterated control = 0 sec, labeled for 1 min and 20 min). The deuteration was quenched by transferring 50 μ L sample to 50 μ L pre-chilled quench buffer (0.2 M TCEP, 6 M guanidine chloride in 100 mM phosphate buffer, pH 2.5) and the mixed sample was incubated at 1.0 °C for two minutes. The quenched sample was then injected into a Waters HDX Manager for online pepsin/protease XIII digestion. The digested peptides were trapped onto an ACQUITY UPLC BEH C18 1.7- μ m, 2.1 $\times$ 5 mm VanGuard pre-column at 0°C and eluted to an analytical column ACQUITY UPLC BEH C18 1.7- μ m, 1.0 $\times$ 50 mm for a 9-minute gradient separation of 5%-40% B (mobile phase A: 0.1% formic acid in water, mobile phase B: 0.1% formic acid in acetonitrile). The mass spectrometer was set at cone voltage of 37 V, scan time of 0.5 s, and mass/charge range of 50-1700 Thomson units (Th).

[0329] For the identification of the peptides from human C5, LC- MS^E data from undeuterated sample were processed and searched against the database including human C5, pepsin, and their randomized sequence via Waters ProteinLynx Global Server (PLGS) software. The identified peptides were imported to DynamX software and filtered by two criteria: (1) minimum products per amino acid = 0.3 and (2) replication file threshold = 3. DynamX software then automatically determined deuterium uptake of each peptide based on retention time and high mass accuracy (<10ppm) across multiple time points with 3 replicates at each time.

[0330] Using the online pepsin/protease XIII column coupled with MS^E data acquisition, total 189 peptides from human C5 were identified in the absence or presence of the antibody, representing 62% sequence coverage. Five peptides had significantly reduced deuteration uptake (centroid delta values > 0.9 daltons with p-values < 0.05) when bound to H4H12166P and are illustrated in the Table 32.

Table 32: Deuteration of Human C5 peptides upon binding to H4H12166P

Residues	1 min Deuteration			20 min Deuteration		
	C5 Centroid H ⁺	C5+H4H12166P Centroid MH ⁺	Δ	C5 Centroid MH ⁺	C5+H4H12166P Centroid MH ⁺	Δ
591-599	1015.38±0.09	1014.44±0.16	-0.93	1015.64±0.04	1014.60±0.08	-1.04
593-599	769.41±0.11	768.33±0.05	-1.08	769.65±0.01	768.30±0.004	-1.35
775-787	1693.81±0.11	1692.85±0.07	-0.96	1694.06±0.04	1692.96±0.02	-1.10
775-794	2439.62±0.29	2438.42±0.20	-1.20	2440.16±0.06	2439.17±0.21	-0.99
779-787	1141.14±0.04	1140.21±0.05	-0.93	1141.23±0.03	1140.21±0.02	-1.02

[0331] The recorded peptide mass corresponds to the average value of the centroid MH⁺ mass from three replicates. These peptides, corresponding to amino acids 591-599 and 775-794, had slower deuteration rate upon binding to H4H12166P. These identified residues also correspond to the residues 591-599 and 775-794 of human C5 as defined by Uniprot entry P01031 (CO5_HUMAN; SEQ ID NO: 359).

Example 14: Effect of anti-C5 antibodies on ocular inflammation in Experimental Autoimmune Uveitis in mice

[0332] The present study was undertaken to evaluate the role of C5 in experimental autoimmune uveitis (EAU). Both genetic [C5 knockout (KO), C3/C5 double KO mice], and pharmacologic (anti-C5 antibody) experimental approaches were used.

Methods

[0333] Adult C57BL/6J mice (n=25, Jackson labs), C5 KO (n=13) and C3/C5 KO (n=8) mice (Regeneron Pharmaceuticals Inc.) were used. EAU was induced by subcutaneous injection of human interphotoreceptor retinoid-binding protein peptide (IRBP, New England Peptide) in complete Freund's adjuvant and intraperitoneal injection of pertussis toxin. Anti-mouse C5 mAb or isotype control mAb was administered through subcutaneous injections every 3 days from day 5 to 28. The anti-mouse C5 antibody used in this study (M1M17628N) comprised a HCVR/LCVR of SEQ ID NOs: 362/363. SPECTRALIS® HRA+OCT (Heidelberg Engineering, Inc.) was used to assess levels of inflammation on days -1, 7, 14, 21 and 28. All animals were euthanized on day 28 for eye and blood collection. Hemolysis assay with/without human C3 was performed to validate complement inhibition. Data were analyzed by ANOVA.

Results

[0334] Compared to wild type mice, inflammation occurrence (30-50%) and vitreous cell cluster counts were significantly decreased in C5 KO mice ($p<0.01$). Optical coherence tomography (OCT) scores in C5 KO mice also significantly reduced 50% at week 3 ($p<0.0001$). Interestingly, in C3/C5 double KO mice, there were significantly more vitreous cell clusters and higher disease scores on day 28 compared to wild type mice ($p<0.05$). In animals that received anti-mC5 Ab (50mg/kg), inflammation incidence and vitreous cell clusters were significantly lower compared to either no treatment or isotype control group on day 21 ($p<0.01$). At weeks 3 and 4, OCT scores in anti-C5 antibody-treated group were significantly lower compared to no treatment or isotype control ($p<0.0001$). (Figure 7) Hemolysis assays with/without human C3 confirmed the inhibition effect of anti-C5 antibody at week 4 (Figure 8).

Conclusion

[0335] Ocular inflammation due to EAU was mitigated by inhibiting C5 activity, either by genetic deletion or pharmacologic inhibition with a specific anti-C5 antibody. C5 depletion delayed EAU occurrence and reduced OCT disease score. These results indicate that C5 is a potential therapeutic target for autoimmune uveitis. Anti-C5 antibody has protective effect on EAU disease in wild type mice. Our findings also suggest that C3 might be beneficial for EAU disease in mice.

Example 15: Effect of anti-human C5 antibodies on Experimental Autoimmune Uveitis

[0336] This Example describes the effects of anti-C5 antibodies against human C5 in a mouse model of experimental autoimmune uveitis (EAU). The mice used for this study were humanized to express human C5 protein using Velocigene® technology (Valenzuela *et al* 2003, Nat. Biotechnol. 21: 652-659). Humanized mice were engineered to replace exon 2 through exon 41 of murine C5 gene with exons 2 – 42 of human C5 gene (disclosed in US Patent Application Publication 2015/0313194, herein incorporated in its entirety).

Methods

[0337] Adult, male mice were immunized subcutaneously in each thigh with 150 µg of human interphotoreceptor retinoid-binding protein (IRBP) peptide 1-20

(GPTHLFQPSLVLDMAKVLLD) (SEQ ID NO: 364) (Avichezer et al 2000, Invest. Ophthalmol. Vis. Sci. 41:127–131) in 0.2 ml emulsion of CFA, supplemented with *Mycobacterium tuberculosis* strain H37RA to 2.5 mg/ml. Mice were then inoculated intraperitoneally with 1.0 µg of pertussis toxin (PTX) to facilitate induction of cell-mediated autoimmunity by promoting a Th1 polarization of the immune response (Thurau et al 1997, Clin. Exp. Immunol. 109: 370-376; Silver et al 1999, Invest. Ophthalmol. Vis. Sci. 40: 2898–2905). The animal body weights were monitored twice a week.

[0338] Ophthalmic examinations were carried out on day -1, before EAU induction and on days 7, 14, 21 and 28. Mice were anesthetized with ketamine (120 mg/kg, IP) and xylazine (5 mg/kg, IP). Pupils were dilated using a 0.5% ophthalmic solution of Tropicamide, and the fundus of the eye was examined using a contact lens with a fundus camera in a Spectralis Heidelberg retinal angiography platform (HRA) + OCT system (Heidelberg Engineering, Carlsbad, CA, USA).

[0339] A series of 61 lateral optical sections were obtained for each eye using the OCT function on the Spectralis HRA + OCT system (Heidelberg Engineering, Carlsbad, CA, USA)). The OCT imaging area was centered on the optic disc allowing for equal imaging above and below the optic nerve head. The retinal thickness was measured as the distance between the bottom of the RPE layer to the inner limiting membrane of the eye. Measurements were taken 1500 µm from the optic disc, and the values from 4 different retinal quadrants (*e.g.*, superior, inferior, temporal and nasal) were averaged for a mean retinal thickness of the eye.

[0340] The severity of inflammatory cell infiltration into the vitreous also was graded in OCT images, by assessing the average number of inflammatory cell clusters in the vitreous, in four lateral OCT scans that transected the optic nerve, per eye.

[0341] An 4-point scale was developed for assessment of disease severity in OCT images (OCT Scores) (Table 33).

Table 33: Scoring EAU in vivo using Optical Coherence Tomography (OCT)

Grade	Criteria
0	No Change
0.5 (Trace)	Minor inflammatory cell infiltration in the vitreous, primarily near the optic nerve head (<15 clusters)
1	Minor inflammatory cell infiltration in the vitreous, primarily near the optic nerve head (<25 clusters); minor focal subretinal lesions (grey spots) in the periphery; minor retinal folds in the periphery; retinal vascular dilation; perivasculitis and vasculitis
2	Moderate inflammatory cell infiltration in the vitreous more diffuse but not in the far periphery (<50 clusters); retinal layer disruptions; small- to medium-sized granuloma formations with retinal folds primarily in the periphery; vessel dilation; minor focal choroidal neovascularization; perivasculitis and vasculitis; minor retinal edema (<10 μ m)
3	Moderate to severe diffuse inflammatory cell infiltration in the vitreous (>50 clusters); diffuse retinal layer disruptions and dilated vessels in the inner nuclear layer; medium- to large- granuloma formations with retinal folds throughout the retina; severe retinal vascular dilation; perivasculitis and vasculitis; moderate diffuse choroidal neovascularization; moderate- to severe- retinal edema (10-40 μ m); minor retinal detachments
4	Severe diffuse inflammatory cell infiltration in the vitreous (>70 clusters); diffuse layer disruptions and dilated vessels in the inner nuclear layer; severe diffuse granuloma formation with retinal folds; severe diffuse choroidal neovascularization; perivasculitis and vasculitis; retinal degeneration or severe retinal edema (>20 μ m loss or >40 μ m gain respectively); large retinal detachments

Statistical Analysis

[0342] Statistical analyses for parametric data (body weight, inflammatory cell clusters in the vitreous, and retinal thickness) were performed by one-way ANOVA test and Tukey's multiple comparison test. For nonparametric data (OCT scores and histology scores) analyses were performed by the Kruskal-Wallis test and Dunn's test with the GraphPad Prism version 5.0d software relative to isotype control or no-treatment groups. Data show mean values $\pm$ SEM. A p-value of less than 0.05 was considered as statistically significant.

Results

[0343] In a first study (Study A), mice were treated subcutaneously every 3 days from day 5 with isotype control antibody (50 mg/kg), or 10 mg/kg or 50 mg/kg of H4H12170P. Treatment with 10 mg/kg H4H12170P resulted in a reduction in inflammation and retinal damage (Figure 9). Mice treated with 10 mg/kg H4H12170P also showed a statistically significant reduction in OCT scores on day 21 and day 28 (Figure 10).

[0344] In a second study (study B), mice were treated subcutaneously every 3 days from day 6 with either isotype control (10 mg/kg), 3 mg/kg or 10 mg/kg of H4H12166P, or with Comparator 2 (see Example 2 herein; “Control Constructs used in the following Examples”). Treatment with H4H12166P either at 3 mg/kg or 10 mg/kg produced a dose-related reduction in OCT scores that was statistically significant on days 14 to 28 (Figure 11). Treatment with 10mg/kg H4H12166P in C5 humanized mice starting 6 days following EAU induction resulted in a dose-related reduction in inflammation and retinal damage as determined by OCT obtained on day 14 to 28 (Figure 12).

[0345] For both studies, non-invasive, in-life evaluation by OCT showed a progressive development of inflammation, increased retinal thickness and morphological abnormalities in control animals following immunization with IRBP.

Conclusion

[0346] These experiments provide further pharmacological evidence that C5 plays a role in the pathogenesis of autoimmune uveitis. Pharmacologic depletion of human C5 by fully human anti-human C5 antibodies postponed EAU incidence and reduced disease severity, establishing the efficacy of these antibodies in autoimmune uveitis.

Example 16: Effect of anti-C5 antibodies on renal ischemia-reperfusion injury

[0347] The present study was carried out to evaluate the role of C5 in renal ischemia-reperfusion injury. Both genetic (using C3 knockout and C5 knockout mice) and pharmacological approaches (using anti-C5 antibodies) were used. Ischemia-reperfusion model was induced by bilateral renal pedicle clamping for 45 min followed by 48 h of reperfusion. Sham laparotomy served as controls. Anti-C5 antibody was administered at 50 mg/kg intravenously as a single dose immediately after ischemia (curative); or subcutaneously as two doses, day -1 and day 1 surgery (preventive). The anti-C5 antibody used for this study was M1M17628N comprising HCVR/LCVR of

SEQ ID NO: 362/363. Blood urea nitrogen (BUN) and serum creatinine markers were used to assess levels of disease and protection in the mice.

Table 34: Percent change in blood urea nitrogen levels in mice treated with anti-C5 antibody (M1M17628N) in preventive and therapeutic modes

BUN, % Change Vs.	RIRI + Veh	RIRI + Iso. Ctl
	Day 2	Day 2
RIRI + M1M17628N (Prev)	-37.19	-34.68
RIRI + M1M17628N (Cur)	- 53.70	-51.85

Table 35: Percent change in serum creatinine levels in mice treated with anti-C5 antibody (M1M17628N) in preventive and therapeutic modes

SCr, % Change Vs.	RIRI + Veh	RIRI + Iso. Ctl
	Day 2	Day 2
RIRI + M1M17628N (Prev)	-53.09	-49.34
RIRI + M1M17628N (Cur)	-59.40	-56.16

[0348] Compared to wild type mice, C3 and C5 knockout mice showed significant functional protection in the RIRI model of acute kidney injury, as evidenced by reduction in the blood urea nitrogen and serum creatinine levels. The anti-C5 antibody showed functional protection in RIRI model in both preventive and therapeutic modes (Tables 34-35).

Example 17: Effect of anti-C5 antibodies on Lupus Nephritis

[0349] This Example describes the efficacy of anti-C5 antibodies in treating lupus nephritis in a mouse model.

[0350] Systemic lupus erythematosus (SLE) is an autoimmune disorder caused by loss of tolerance to self-antigens, the production of autoantibodies and deposition of complement-fixing immune complexes (ICs) in injured tissues. SLE is characterized by a wide range of clinical manifestations and targeted organs, with lupus nephritis being one of the most serious complications. Complement activation in the kidneys of lupus nephritis patients contributes to inflammation and tissue damage. The efficacy of anti-

C5 antibodies in treating lupus nephritis was studied in NZBWF1 mice, a spontaneous mouse model of lupus nephritis (Yang et al 1996, PNAS). The mice develop autoimmune disease resembling human SLE, autoantibodies to nuclear antigens and cell membrane proteins, hypergammaglobulinemia, albuminuria, proteinuria, initiate immune complex glomerulonephritis and die of kidney failure and end-stage renal disease at 35 to 50 weeks of age.

[0351] For this study, 25-week old NZBWF1 mice were subcutaneously treated with 30 mg/kg of isotype control, or anti-C5 antibodies twice a week for 8 weeks followed by thrice a week for 10 weeks. The anti-mouse C5 antibodies used for this study were M1M17628N and M1M17627N, comprising HCVR/LCVR of SEQ ID NOs: 362/363 and 365/366, respectively.

[0352] Treatment with anti-C5 antibodies significantly improved survival rate in mice (Figure 13). Both antibodies improved albuminuria at 8-14 weeks of treatment (Figure 14), and blood urea nitrogen levels at 12-16 weeks of treatment (Figure 15).

Example 18: Effect of anti-C5 antibodies against astrocyte cell death

[0353] Neuromyelitis optica (NMO) is an autoimmune disease of the central nervous system (CNS) that mainly affects the optic nerve and spinal cord. In NMO, anti-aquaporin-4 autoantibodies (AQP4-Ab) cause damage to astrocytes by activating complement-dependent cytotoxicity (CDC). The goals of this study were to evaluate the role of the complement system in NMO progression and the use of an antibody against a complement protein as a potential therapeutic treatment for NMO.

[0354] Primary rat cortical astrocytes were obtained from cerebral brain cortex of post-natal rat pups and were cultured with AQP4-Ab (antibody "rAb-53" from US Patent Application Publication 2014/0170140; Bennett et al 2009, Ann. Neurol. 66: 617-629) and complement proteins to demonstrate cell-mediated cytotoxicity. Then the experiments were repeated with addition of an anti-C5 antibody to demonstrate blocking of the astrocyte cell destruction.

[0355] To quantify cell death, a CytoTox-Glo™ luminescence cytotoxicity assay was performed. The assay used various concentrations of anti-C5 antibody (0.001µg/ml, 0.01µg/ml, 0.1µg/ml, 1µg/ml, 10µg/ml, 100µg/ml, or 1000µg/ml) or an isotype control antibody.

[0356] In order to determine whether anti-C5 antibody could block the AQP4-Ab induced CDC, astrocytes were plated and the CytoTox-Glo™ Cytotoxicity Assay was repeated to find an optimal dose of AQP4-Ab for that plating. The optimal concentration of AQP4-Ab was found to be 50 µg/mL, and in a following experiment a constant dose of AQP4-Ab (50 µg/mL) was used, while the dose of anti-C5 antibody was varied. As shown in Figure 16, a decrease in RLU was seen (on average 300k to on average 100k) with increasing amounts of anti-C5 antibody demonstrating that the anti-C5 antibody blocked astrocyte cell death. For both experiments, the RLU did not vary with the isotype control antibody. As shown in Figure 16, anti-C5 antibodies inhibited AQP4 Ab induced cytotoxicity on primary cortical astrocyte with IC₅₀ of 15-17 nM.

[0357] In a subsequent study, anti-AQP4 antibody and anti-C5 antibody will be injected into rat brains to assess the therapeutic efficacy against complement-mediated cytotoxicity of astrocytes in CNS.

Example 19: Endothelial assay

[0358] This Example describes an in vitro glomerular endothelial assay to examine if anti-C5 antibodies block C5b-9 and C3 deposition.

[0359] Reproducible methods for evaluating inhibitory effects of drug candidates on complement activation are essential for preclinical development. Due to the complexity of complement activation pathways, an assay should use relevant cells and endpoints to the given therapeutic indication. Here, using an immortalized human glomerular endothelial cell line (HGECS), a complement C3 & C5 deposition model was validated for use evaluating the blocking activity of anti-C3 or C5 mAbs.

Methods

[0360] Human primary kidney glomerular endothelial cells (HGEC; Cell Biologics) were plated overnight in complete media into collagen I – coated black clear bottom 96-well plates. The cells were treated with either PBS (control) or activated for 10 mins with 10uM ADP. After PBS washing, 50% human serum (complement-preserved, C3-depleted, or C5-depleted) was added for 4 hours. Anti-C5 antibodies were added at 1 mg/mL to the serum prior to the treatment. The cells were washed and fixed and probed with anti-C3b antibodies (ThermoFisher) and/or anti-C5b-9 antibodies (Abcam), secondary antibodies and counterstained with DAPI. Images were captured on

ImagExpress and high content image analysis was used to quantify fluorescent staining for each image and averaged per condition.

Results

[0361] C3 and C5b-9 deposition was observed on ADP-activated HGECs exposed to normal human serum but not on non-activated HGECs (C3: $1.5 \times 10^7 \pm 1.0 \times 10^7$; C5: $7.9 \times 10^6 \pm 6.6 \times 10^6$, $P < 0.05$ vs non-ADP-activated HGEC). The deposition of C3 and C5b-9 were significantly reduced on ADP-activated HGEC exposed to C3 or C5 depleted serum (C3: $3.3 \times 10^5 \pm 4.8 \times 10^4$; C5: $1.5 \times 10^6 \pm 6.0 \times 10^5$, $P < 0.05$). Addition of a blocking anti-C5 mAb significantly reduced normal human serum derived C5b-9 deposition onto ADP-activated HGEC, deposition was comparable to C5 depleted sera (C5 mAb: $1.02 \times 10^6 \pm 6.0 \times 10^5$, Control mAb $3.7 \times 10^6 \pm 1.6 \times 10^6$, $P < 0.05$ vs. control mAb).

Conclusion

[0362] These data demonstrate the utility of an *in vitro* human glomerular endothelial assay to model complement C3 & C5 deposition. In addition to in-vitro screening, this assay offers potential as a translational model to evaluate anti-complement strategies in renal disease using patient derived serum samples.

[0363] The present invention is not to be limited in scope by the specific embodiments described herein. Indeed, various modifications of the invention in addition to those described herein will become apparent to those skilled in the art from the foregoing description and the accompanying figures. Such modifications are intended to fall within the scope of the appended claims.