ANTI-GITR ANTIBODIES AND USES THEREOF

FIELD

[0001] The present invention relates to antibodies and antigen-binding fragments thereof that specifically bind glucocorticoid-induced tumor necrosis factor receptor (GITR) and methods of use thereof.

BACKGROUND

[0002] Glucocorticoid-induced tumor necrosis factor receptor (GITR) is a member of the tumor necrosis factor receptor superfamily (TNFRSF). GITR expression is constitutively high on regulatory T cells, low/intermediate on naïve T cells, NK cells and granulocytes, and inducible upon activation. GITR interacts with its ligand GITRL, which is mainly expressed on antigen-presenting cells. GITR receptor activation can both augment effector T-cell proliferation and function as well as attenuate the suppression induced by regulatory T cells. Consequently, the modulation of GITR activity can serve as a basis for cancer immunotherapy and immune disorders. Thus, there is a need for agents, *e.g.*, antibodies that modulate the activity of GITR.

BRIEF SUMMARY

[0003] The present invention provides antibodies and antigen-binding fragments thereof that bind glucocorticoid-induced tumor necrosis factor receptor (GITR). The antibodies of the invention are useful, *inter alia*, for targeting immune cells, *e.g.*, effector T-cells, regulatory T-cells, and NK cells that express GITR.

[0004] 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 eliminate residual effector functions (Reddy *et al.*, 2000, J. Immunol. 164:1925-1933).

[0005] Exemplary anti-GITR 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 the exemplary anti-GITR 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-GITR antibodies.

[0006] The present invention provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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.

[0007] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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.

[0008] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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-GITR antibodies listed in Table 1. In certain embodiments, the HCVR/LCVR amino acid sequence pair is selected from the group consisting of: 98/106; 162/170; 194/202; 242/250; 290/298; 338/402; and 346/402.

[0009] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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.

[0010] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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.

[0011] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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.

[0012] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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.

[0013] The present invention also provides antibodies or antigen-binding fragments thereof

that specifically bind GITR, 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.

[0014] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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.

[0015] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, 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-GITR antibodies listed in Table 1. In certain embodiments, the HCDR3/LCDR3 amino acid sequence pair is selected from the group consisting of: 104/112; 168/176; 200/208; 248/256; 296/304; 344/408; and 352/408.

[0016] The present invention also provides antibodies or antigen-binding fragments thereof that specifically bind GITR, comprising a set of six CDRs (*i.e.*, HCDR1-HCDR2-HCDR3-LCDR1-LCDR2-LCDR3) contained within any of the exemplary anti-GITR antibodies listed in Table 1. In certain embodiments, the HCDR1-HCDR2-HCDR3-LCDR1-LCDR2-LCDR3 amino acid sequences set is selected from the group consisting of: 100-102-104-108-110-112; 164-166-168-172-174-176; 196-198-200-204-206-208; 244-246-248-252-254-256; 292-294-296-300-302-304; 340-342-344-404-406-408; and 348-350-352-404-406-408.

[0017] In a related embodiment, the present invention provides antibodies, or antigen-binding fragments thereof that specifically bind GITR, 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-GITR antibodies listed in Table 1. For example, the present invention includes antibodies or antigen-binding fragments thereof that specifically bind GITR, 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: 98/106; 162/170; 194/202; 242/250; 290/298; 338/402; and 346/102. 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.

[0018] The present invention also provides nucleic acid molecules encoding anti-GITR 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.

[0019] 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.

[0020] 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.

[0021] 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.

[0022] 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.

[0023] 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.

[0024] 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.

[0025] 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.

[0026] 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-GITR antibodies listed in Table 1.

[0027] 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-GITR antibodies listed in Table 1.

[0028] 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 2, 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-GITR antibody listed in Table 1.

[0029] The present invention also provides recombinant expression vectors capable of expressing a polypeptide comprising a heavy or light chain variable region of an anti-GITR 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 1. 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.

[0030] The present invention includes anti-GITR 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).

[0031] In another aspect, the invention provides a pharmaceutical composition comprising a recombinant human antibody or fragment thereof which specifically binds GITR and a pharmaceutically acceptable carrier. In a related aspect, the invention features a composition which is a combination of an anti-GITR antibody and a second therapeutic agent. In one embodiment, the second therapeutic agent is any agent that is advantageously combined with an anti-GITR antibody. The present invention also provides antibody-drug conjugates (ADCs) comprising an anti-GITR antibody conjugated to a cytotoxic agent. Exemplary combination therapies, co-formulations, and ADCs involving the anti-GITR antibodies of the present invention are disclosed elsewhere herein.

[0032] In yet another aspect, the invention provides therapeutic methods for killing tumor cells or for inhibiting or attenuating tumor cell growth, or otherwise treating a patient afflicted with cancer, using an anti-GITR antibody or antigen-binding portion of an antibody of the invention. The therapeutic methods according to this aspect of the invention comprise administering a therapeutically effective amount of a pharmaceutical composition comprising an antibody or antigen-binding fragment of an antibody of the invention to a subject in need thereof. The disorder treated is any disease or condition which is improved, ameliorated, inhibited or prevented by targeting GITR and/or by increasing T-cell proliferation or function and/or inhibiting suppression activity induced by regulatory T cells.

[0033] In yet another aspect, the invention provides therapeutic methods for killing tumor cells or for inhibiting or attenuating tumor cell growth, or otherwise treating a patient afflicted with cancer, using a combination of an anti-GITR antibody or antigen-binding portion of an anti-GITR antibody and an anti-PD1 antibody or antigen-binding portion of an anti-PD1 antibody. The therapeutic methods according to this aspect of the invention comprise administering a therapeutically effective amount of a pharmaceutical composition comprising a combination of an anti-GITR and anti-PD1 antibody or antigen-binding fragment

composition to a subject in need thereof. The disorder treated is any disease or condition which is improved, ameliorated, inhibited or prevented by targeting both GITR and PD1.

[0034] Other embodiments will become apparent from a review of the ensuing detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] Figure 1 depicts average tumor volumes for each treatment group (mm^3 ± SEM) plotted against days after tumor challenge as described in Example 7. Mice were treated with either isotype antibody (open circles, ○), anti-PD-1 antibody (open squares, □), anti-GITR antibody (open pyramids, Δ), or a combination of anti-PD-1 and anti-GITR (closed inverted pyramids, ▼).

[0036] Figure 2 depicts survival analysis of MC38 bearing mice treated with the combination of an anti-mouse GITR and anti-mouse- PD1 antibody as described in Example 7. Mice were treated with either isotype antibody (open circles, ○), anti-PD-1 antibody (open squares, □), anti-GITR antibody (open pyramids, Δ), or a combination of anti-PD-1 and anti-GITR (open inverted pyramids, ▽).

[0037] Figure 3 depicts the individual tumor growth curve of tumor-free or naïve control mice challenged with MC38 or B16.F10.9 tumor cells as described in Example 7.

[0038] Figure 4 depicts average tumor volumes for mice treated with different depletion antibodies as described in Example 7.

[0039] Figure 5 depicts FACS analysis result of intratumoral CD8/Treg, CD4 T*eff*/T*reg* ratio as described in Example 7.

[0040] Figure 6 depicts percentage and cell number/mm^3 tumor of T cell subsets in tumor as described in Example 7.

[0041] Figure 7 depicts average tumor volumes for each treatment group (mm^3 ± SEM) plotted against days after tumor challenge as depicted in Example 7.

[0042] Figure 8 depicts survival analysis of MC38 bearing GITR/GIRL humanized mice treated with the combination of an anti-human GITR- and anti-mouse PD1-antibody as described in Example 7.

[0043] Figure 9 depicts FACS analysis of intratumoral and spleen percentage of CD8 T cells, percentage of T*reg* cells, and CD8/T*reg* ratio as described in Example 7.

[0044] Figure 10 depicts average tumor volumes for each treatment group (mm^3 ± SEM) plotted against days after tumor challenge as described in Example 7.

[0045] Figure 11 depicts survival analysis of MC38 bearing PD1/PDL1 humanized mice treated with the combination of an anti-mouse GITR- and anti-human PD1-antibody as described in Example 7.

[0046] Figure 12 depicts a tumor growth curve of MC38-bearing mice as described in

Example 7. The Y-axis depicts tumor volume in cubic millimeters and the X-axis depicts time in days post tumor challenge. Open symbols (□, ○) represent mice first treated with an isotype antibody (control). Filled symbols (■, ●) represent mice first treated with an anti-CD226 antibody. Those mice then treated with the isotype antibody are represented by circles (○, ●) and solid lines. Those mice then treated with the anti-GITR and anti-PD-1 combination are represented by squares (□, ■) and dotted lines.

[0047] Figure 13 depicts a survival curve of MC38-bearing mice as described in Example 7. The Y-axis depicts percent survival and the X-axis depicts time in days post tumor challenge. Open symbols (□, ○) represent mice first treated with an isotype antibody (control). Filled symbols (■, ●) represent mice first treated with an anti-CD226 antibody. Those mice then treated with the isotype antibody are represented by circles (○, ●) and solid lines. Those mice then treated with the anti-GITR and anti-PD-1 combination are represented by squares (□, ■) and dotted lines.

[0048] Figure 14 depicts a tumor growth curve of MC38-bearing wild type mice (represented by diamonds [◇◆]) or TIGIT knock-out mice (represented by triangles [△▲]) treated with isotype IgGs as described in Example 7. The Y-axis depicts tumor volume in cubic millimeters and the X-axis depicts time in days post tumor challenge. Open symbols and dotted lines represent mice first treated with an isotype antibody (control). Filled symbols and solid lines represent mice first treated with an anti-CD226 antibody.

[0049] Figure 15 depicts a tumor growth curve of MC38-bearing wild type mice (represented by circles [○, ●]) or TIGIT knock-out mice (represented by inverted triangles [▽▼]) treated with isotype IgGs as described in Example 7. The Y-axis depicts tumor volume in cubic millimeters and the X-axis depicts time in days post tumor challenge. Open symbols and dotted lines represent mice first treated with an isotype antibody (control). Filled symbols and solid lines represent mice first treated with an anti-CD226 antibody.

[0050] Figure 16 includes cumulative distribution function (CDF) plots depicting the upregulated expression of CD226 by combination treatment in total (Panel A), clonal expanded (Panel B), or non-expanded (Panel C) CD8+ T cells. The X-axis depicts CD226 expression in log2(RPKM) (Reads Per Kilobase of transcript per Million mapped reads) and the Y-axis depicts cumulative frequency. The red line represents the anti-GITR / anti-PD1 treatment; the black line represents isotype antibody treatment; the blue line represents anti-GITR treatment; and the purple line represents anti-PD1 treatment.

[0051] Figure 17 is a Western blot depicting the relative expression of phospho-CD3ζ and phospho-CD226 as a function of PD-1 concentration.

[0052] Figure 18, Panels A-D depict bar charts of the number of T-cell types produced in wildtype (open bars) and CD226 knock out mice (solid bars). Panel A is a bar chart depicting FACS analysis (number of cells) of T cell development in thymus (Tconv, conventional T

cells; DP, CD4/CD8 double positive; SP, single positive; DN, CD4/CD8 double negative). Panel B is a bar chart depicting FACS validation (number of cells) of the population of T cell subsets in spleen and blood in wildtype and CD226-/- animals. Panel C is a bar chart depicting FACS analysis (MFI, mean fluorescence intensity) of T cell subsets in spleen and blood that express PD1. Panel D is a bar chart depicting FACS analysis (MFI) of T cell subsets in spleen and blood that express GITR. Panels E-I are bar charts depicting inflammatory cytokine secretion in picograms per milliliter upon *ex vivo* TCR stimulation of splenocytes with anti-CD3 + anti-CD28 Ab for 16 hours. Splenocytes from CD226-/- (solid bars) or wild type (WT) (open bars) mice were stimulated with anti-CD3 + anti-CD28 Ab for 16 hours. Panel E = IFN-γ; panel F = IL-2; panel G = TNF-α; panel H = IL-6; and panel I = IL-5.

[0053] Figure 19 is a line graph depicting percent animal survival as a function of time in days post tumor challenge. Panel A depicts CD226 KO mice (rose lines) or WT littermates (black lines) challenged with MC38 tumor cells and treated with either anti-GITR + anti-PD-1 Ab (filled circles and squares) or isotype Abs (open circles and squares). Panels B-D depict the effect of antibody treatment on (B) animals treated with antibodies blocking CD28 signaling (10 mg/kg CTLA-4-Ig; panel B, green lines); (C) animals treated with antibodies blocking OX40 signaling (10 mg/kg OX40L blocking antibody; panel C); and (D) animals treated with antibodies blocking 4-1BB signaling (10 mg/kg 4-1BBL blocking antibody; panel D).

[0054] Figure 20 is a line graph depicting tumor size (in cubic millimeters) as a function of days after tumor challenge for mice treated with isotype (open circles and black line), anti-PD1 (open squares, red line), anti-GITR (open upright pyramids and green line), and anti-GITR / anti-PD1 combination therapy (open inverted pyramids and blue lines). Panel A represents MC38 tumors not expressing CD155. Panel B represents MC38 tumors expressing CD155.

[0055] Figure 21 is a bar chart depicting the number of cells expressing CD226 (Panel A), 4-1BB (Panel B), and IFN-γ (Panel C) from animals challenged with MC38 tumor cells over expressing CD155 (filled bars) and MC38 tumor cells that do not express CD155 (open bars).

[0056] Figure 22 depicts a dot plot RNA-seq analysis of cancer patient tumor biopsies showing CD226 RNA expression (in log2[RPKM]) as a function of anti-PD-1 Ab treatment.

DETAILED DESCRIPTION

[0057] Before the present invention is 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.

[0058] 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. As used herein, the term "about," when used in reference to a particular recited numerical value, means that the value may vary from the recited value by no more than 1%. For example, as used herein, the expression "about 100" includes 99 and 101 and all values in between (*e.g.*, 99.1, 99.2, 99.3, 99.4, etc.).

[0059] Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, the preferred methods and materials are now described. All patents, applications and non-patent publications mentioned in this specification are incorporated herein by reference in their entireties.

Definitions

[0060] The expression glucocorticoid-induced tumor necrosis factor receptor, "GITR," and the like, as used herein, refers to the human glucocorticoid-induced tumor necrosis factor receptor, comprising the amino acid sequence as set forth in SEQ ID NO: 413 (NCBI Accession #NP_004186.1). The expression "GITR" includes both monomeric and multimeric GITR molecules. As used herein, the expression "monomeric human GITR" means a GITR protein or portion thereof that does not contain or possess any multimerizing domains and that exists under normal conditions as a single GITR molecule without a direct physical connection to another GITR molecule. An exemplary monomeric GITR molecule is the molecule referred to herein as "hGITR.mmh" comprising the amino acid sequence of SEQ ID NO: 409 (*see*, *e.g.*, Example 3, herein). As used herein, the expression "dimeric human GITR" means a construct comprising two GITR molecules connected to one another through a linker, covalent bond, non-covalent bond, or through a multimerizing domain such as an antibody Fc domain. Exemplary dimeric GITR molecules include those molecules referred to herein as "hGITR.mFc" and “hGITR.hFc”, comprising the amino acid sequence of SEQ ID NO: 410 and SEQ ID NO: 411 respectively (*see*, *e.g.*, Example 3, herein).

[0061] All references to proteins, polypeptides and protein fragments herein are intended to refer to the human version of the respective protein, polypeptide or protein fragment unless explicitly specified as being from a non-human species. Thus, the expression "GITR" means human GITR unless specified as being from a non-human species, *e.g.*, "mouse GITR," "monkey GITR," etc.

[0062] As used herein, the expression "cell surface-expressed GITR" means one or more GITR protein(s), or the extracellular domain thereof, that is/are expressed on the surface of a cell *in vitro* or *in vivo*, such that at least a portion of a GITR protein is exposed to the

extracellular side of the cell membrane and is accessible to an antigen-binding portion of an antibody. A "cell surface-expressed GITR" can comprise or consist of a GITR protein expressed on the surface of a cell which normally expresses GITR protein. Alternatively, "cell surface-expressed GITR" can comprise or consist of GITR protein expressed on the surface of a cell that normally does not express human GITR on its surface but has been artificially engineered to express GITR on its surface.

[0063] As used herein, the expression "anti-GITR antibody" includes both monovalent and monospecific bivalent antibodies with a single specificity, as well as bispecific antibodies comprising a first arm that binds GITR and a second arm that binds a second (target) antigen, wherein the anti-GITR arm comprises any of the HCVR/LCVR or CDR sequences as set forth in Table 1 herein. The expression "anti-GITR antibody" also includes antibody-drug conjugates (ADCs) comprising an anti-GITR antibody or antigen-binding portion thereof conjugated to a drug or toxin (*i.e.,* cytotoxic agent). The expression "anti-GITR antibody" also includes antibody-radionuclide conjugates (ARCs) comprising an anti-GITR antibody or antigen-binding portion thereof conjugated to a radionuclide.

[0064] The term "antibody", as used herein, means any antigen-binding molecule or molecular complex comprising at least one complementarity determining region (CDR) that specifically binds to or interacts with a particular antigen (*e.g.*, GITR). The term "antibody" includes immunoglobulin molecules comprising four polypeptide chains, two heavy (H) chains and two light (L) chains inter-connected by disulfide bonds, as well as multimers thereof (*e.g.*, IgM). Each heavy chain comprises a heavy chain variable region (abbreviated herein as HCVR or V_H) and a heavy chain constant region. The heavy chain constant region comprises three domains, C_H1, C_H2 and C_H3. Each light chain comprises a light chain variable region (abbreviated herein as LCVR or V_L) and a light chain constant region. The light chain constant region comprises one domain (C_L1). The V_H and V_L regions can be further subdivided into regions of hypervariability, termed complementarity determining regions (CDRs), 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 different embodiments of the invention, the FRs of the anti-GITR antibody (or antigen-binding portion 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.

[0065] The term "antibody", as used herein, also includes antigen-binding fragments of full antibody molecules. 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. 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.

[0066] 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.

[0067] 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.

[0068] 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)).

[0069] As with full antibody molecules, antigen-binding fragments may be monospecific or multispecific (*e.g.*, bispecific). A multispecific 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 multispecific antibody format, including the exemplary bispecific 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.

[0070] The antibodies of the present invention may function through complement-dependent cytotoxicity (CDC) or antibody-dependent cell-mediated cytotoxicity (ADCC). "Complement-dependent cytotoxicity" (CDC) refers to lysis of antigen-expressing cells by an antibody of the invention in the presence of complement. "Antibody-dependent cell-mediated cytotoxicity" (ADCC) refers to a cell-mediated reaction in which nonspecific cytotoxic cells that express Fc receptors (FcRs) (*e.g.*, Natural Killer (NK) cells, neutrophils, and macrophages) recognize bound antibody on a target cell and thereby lead to lysis of the target cell. CDC and ADCC can be measured using assays that are well known and available in the art. (*See*, *e.g.*, U.S. Patent Nos 5,500,362 and 5,821,337, and Clynes *et al.* (1998) Proc. Natl. Acad. Sci. (USA) *95*:652-656). The constant region of an antibody is important in the ability of an antibody to fix complement and mediate cell-dependent cytotoxicity. Thus, the isotype of an antibody may be selected on the basis of whether it is desirable for the antibody to mediate cytotoxicity.

[0071] In certain embodiments of the invention, the anti-GITR antibodies of the invention are human antibodies. 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 antibodies 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 antibodies in which CDR sequences derived from the germline of another mammalian species, such as a mouse, have been grafted onto human

framework sequences. The term “human antibody” does not include naturally occurring molecules that normally exist without modification or human intervention/manipulation, in a naturally occurring, unmodified living organism.

[0072] The antibodies of the invention may, in some embodiments, be recombinant human antibodies. The term "recombinant human antibody", as used herein, is intended to include all human antibodies that are prepared, expressed, created or isolated by recombinant means, such as antibodies expressed using a recombinant expression vector transfected into a host cell (described further below), antibodies isolated from a recombinant, combinatorial human antibody library (described further below), antibodies isolated from an animal (*e.g.*, a mouse) that is transgenic for human immunoglobulin genes (see *e.g.*, Taylor *et al.* (1992) Nucl. Acids Res. 20:6287-6295) or antibodies prepared, expressed, created or isolated by any other means that involves splicing of human immunoglobulin gene sequences to other DNA sequences. Such recombinant human antibodies have variable and constant regions derived from human germline immunoglobulin sequences. In certain embodiments, however, such recombinant human antibodies are subjected to *in vitro* mutagenesis (or, when an animal transgenic for human Ig sequences is used, *in vivo* somatic mutagenesis) and thus the amino acid sequences of the V_H and V_L regions of the recombinant antibodies are sequences that, while derived from and related to human germline V_H and V_L sequences, may not naturally exist within the human antibody germline repertoire *in vivo*.

[0073] Human antibodies can exist in two forms that are associated with hinge heterogeneity. In one form, an immunoglobulin molecule comprises a stable four chain construct of approximately 150-160 kDa in which the dimers are held together by an interchain heavy chain disulfide bond. In a second form, the dimers are not linked via inter-chain disulfide bonds and a molecule of about 75-80 kDa is formed composed of a covalently coupled light and heavy chain (half-antibody). These forms have been extremely difficult to separate, even after affinity purification.

[0074] The frequency of appearance of the second form in various intact IgG isotypes is due to, but not limited to, structural differences associated with the hinge region isotype of the antibody. A single amino acid substitution in the hinge region of the human IgG4 hinge can significantly reduce the appearance of the second form (Angal *et al.* (1993) Molecular Immunology 30:105) to levels typically observed using a human IgG1 hinge. The instant invention encompasses antibodies having one or more mutations in the hinge, C_H2 or C_H3 region which may be desirable, for example, in production, to improve the yield of the desired antibody form.

[0075] The antibodies of the invention may be isolated antibodies. An "isolated antibody," as used herein, means an antibody that has been identified and separated and/or recovered

from at least one component of its natural environment. For example, an antibody that has been separated or removed from at least one component of an organism, or from a tissue or cell in which the antibody naturally exists or is naturally produced, is an "isolated antibody" for purposes of the present invention. An isolated antibody also includes an antibody *in situ* within a recombinant cell. Isolated antibodies are antibodies that have been subjected to at least one purification or isolation step. According to certain embodiments, an isolated antibody may be substantially free of other cellular material and/or chemicals.

[0076] The anti-GITR 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 from which the antibodies were derived. 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.

[0077] The present invention also includes anti-GITR 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-GITR 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 set forth in Table 1 herein.

[0078] 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. Epitopes may be either conformational or linear. A conformational epitope is produced by spatially juxtaposed amino acids from different segments of the linear polypeptide chain. A linear epitope is one produced by adjacent amino acid residues in a polypeptide chain. In certain circumstance, an epitope may include moieties of saccharides, phosphoryl groups, or sulfonyl groups on the antigen.

[0079] 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 95%, and more preferably at least about 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.

[0080] 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 95% sequence identity, even more preferably at least 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 sequence identity 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, 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 are 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: 1443-1445, herein incorporated by reference. A "moderately conservative" replacement is any change having a nonnegative value in the PAM250 log-likelihood matrix.

[0081] Sequence similarity for polypeptides, which is also referred to as sequence identity, 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 using 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 Altschul *et al.* (1997) Nucleic Acids Res. 25:3389-402, each herein incorporated by reference.

Anti-GITR Antibodies Comprising Fc Variants

[0082] According to certain embodiments of the present invention, anti-GITR 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-GITR 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.,* H/F or Y); 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).

[0083] For example, the present invention includes anti-GITR 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); 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.

Biological Characteristics of the Anti-GITR Antibodies

[0084] The present invention includes antibodies and antigen-binding fragments thereof that bind monomeric human GITR with high affinity. For example, the present invention includes anti-GITR antibodies that bind monomeric human GITR (*e.g.*, hGITR.mmh) with a K_D of less than about 5.0 nM as measured by surface plasmon resonance at 37ºC, *e.g.*, using an assay format as defined in Example 3 herein, or a substantially similar assay. In some embodiments, anti-GITR antibodies are provided that bind monomeric human GITR at 37ºC with a K_D of less than about 4 nM, less than about 3 nM, less than about 2 nM, or less than about 1.50 nM as measured by surface plasmon resonance, *e.g.*, using an assay format as defined in Example 3 herein, or a substantially similar assay.

[0085] The present invention also includes antibodies and antigen-binding fragments thereof that bind monomeric human GITR (*e.g.*, hGITR.mmh) with a dissociative half-life (t½) of greater than about 12 minutes as measured by surface plasmon resonance at 37ºC, *e.g.*, using an assay format as defined in Example 3 herein, or a substantially similar assay.

According to certain embodiments, anti-GITR antibodies are provided that bind monomeric human GITR at 37ºC with a t½ of greater than about 12 minutes, greater than about 13 minutes, greater than about 14 minutes, greater than about 15 minutes, or longer, as measured by surface plasmon resonance, *e.g.*, using an assay format as defined in Example 3 herein, or a substantially similar assay.

[0086] The present invention also includes antibodies and antigen-binding fragments thereof that bind dimeric human GITR (*e.g.*, hGITR.mFc) with high affinity. For example, the present invention includes anti-GITR antibodies that bind dimeric human GITR with a K_D of less than about 950 pM as measured by surface plasmon resonance at 37ºC, *e.g.*, using an assay format as defined in Example 3 herein, or a substantially similar assay. According to certain embodiments, anti-GITR antibodies are provided that bind dimeric human GITR at 37ºC with a K_D of less than about 900 pM, less than about 850 pM, less than about 800 pM, less than about 700 pM, less than about 600 pM, less than about 500 pM, less than about 400 pM, less than about 300 pM, less than about 200 pM, or less than about 100 pM as measured by surface plasmon resonance, *e.g.*, using an assay format as defined in Example 3 herein, or a substantially similar assay.

[0087] The present invention also includes antibodies and antigen-binding fragments thereof that bind dimeric human GITR (*e.g.*, hGITR.mFc) with a dissociative half-life (t½) of greater than about 7 minutes as measured by surface plasmon resonance at 37ºC, *e.g.*, using an assay format as defined in Example 3 herein, or a substantially similar assay. According to certain embodiments, anti-GITR antibodies are provided that bind dimeric human GITR at 37ºC with a t½ of greater than about 10 minutes, greater than about 20 minutes, greater than about 30 minutes, greater than about 40 minutes, greater than about 50 minutes, greater than about 60 minutes, greater than about 70 minutes, greater than about 80 minutes, greater than about 90 minutes, greater than about 100 minutes, or longer, as measured by surface plasmon resonance, *e.g.*, using an assay format as defined in Example 3 herein, or a substantially similar assay.

[0088] The present disclosure also includes antibodies and antigen-binding fragments thereof that bind cell-surface-expressed GITR. For example, antibodies that bind to human GITR transfected embryonic kidney 293 (HEK-293) D9 cells with high affinity are provided herein. For example, the instant disclosure includes anti-GITR antibodies that bind human GITR transfected embryonic kidney 293 (HEK-293) D9 cells with an EC_{50} of less than about 260 pM as measured by electrochemiluminescence, *e.g.*, using an assay format as defined in Example 4 herein, or a substantially similar assay. In certain embodiments, anti-GITR antibodies are provided that bind human GITR transfected embryonic kidney 293 (HEK-293) D9 cells with an EC_{50} of less than about 250 pM, less than about 240 pM, less than about 230 pM, or less than about 220 pM as measured by electrochemiluminescence, *e.g.*, using

an assay format as defined in Example 4 herein, or a substantially similar assay.

[0089] The antibodies of the present invention may possess one or more of the aforementioned biological characteristics, or any combination thereof. The foregoing list of biological characteristics of the antibodies of the invention is not intended to be exhaustive. 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.

Fc anchoring-dependent and anchoring-independent GITR activation and GITRL blocking

[0090] The present disclosure includes antibodies and antigen-binding fragments thereof that activate human GITR, *e.g.*, as determined in the assay formats described in Example 5 and/or Example 6 herein, or in a substantially similar assay format. As used herein, "activates human GITR" refers to the activation of GITR via binding to its cognate ligand, GITR Ligand (GITRL) or to the binding of agonist anti-GITR antigen binding protein(s) to GITR. With regard to activation of GITR by agonist anti-GITR binding proteins, "activation" can be in the presence or absence of antigen-binding protein anchoring to Fc gamma receptors. Human GITR activation is manifested in the exhibition of certain biological activities, including but not limited to the induction or enhancement of GITR signaling *in vitro* or *in vivo*, the reduction of regulatory T cell suppression of effector T cell activity; the decrease of circulating T *reg* levels *in vitro* or *in vivo*, the decrease of intratumoral T *regs in vivo*, the activation of effector T cells *in vitro* or *in vivo*, the induction or enhancement of effector T cell proliferation *in vitro* or *in vivo*, or the inhibition or reduction of tumor growth *in vivo*.

GITR activation in the absence of Fc Anchoring

[0091] In some embodiments, the antibodies and antigen-binding fragments thereof provided herein activate human GITR in the absence of Fc anchoring, *e.g.*, as determined in the assay formats described in Example 5 and/or Example 6 herein, or in a substantially similar assay format. As used herein, "in the absence of Fc anchoring" refers to the activation of GITR and GITR-mediated signaling or blocking of GITRL without the clustering of anti-GITR antibodies by different forms of the Fc gamma receptor and can be determined and quantified via, *e.g.*, the activation of primary T-cells co-cultured *in vitro* in the absence of cell-surface bound Fc gamma receptor(s). In some embodiments, the antibody or antigen-binding fragment thereof activates human GITR at an activation percentage greater than about 25% at an EC_{50} of less than about 3 nM in the absence of Fc anchoring, as determined by NFκB reporter assay, *e.g.*, as described in Example 5 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment thereof

activates human GITR at an activation percentage greater than about 30%, greater than about 40%, greater than about 50%, greater than about 60%, or greater than about 65% at an EC_{50} of less than about 3 nM in the absence of Fc anchoring as determined by NFκB reporter assay, *e.g.*, as described in Example 5 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment thereof activates human GITR at an activation percentage greater than about 30%, greater than about 40%, greater than about 50%, greater than about 60%, or greater than about 65% at an EC_{50} of less than about 2 nM in the absence of Fc anchoring as determined by NFκB reporter assay, *e.g.*, as described in Example 5 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment thereof activates human GITR at an activation percentage greater than about 30%, greater than about 40%, greater than about 50%, greater than about 60%, or greater than about 65% at an EC_{50} of less than about 1.5 nM in the absence of Fc anchoring as determined by NFκB reporter assay, *e.g.*, as described in Example 5 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment thereof activates human GITR at an activation percentage greater than about 30%, greater than about 40%, greater than about 50%, greater than about 60%, or greater than about 65% at an EC_{50} of less than about 1.4 nM in the absence of Fc anchoring as determined by NFκB reporter assay, *e.g.*, as described in Example 5 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment thereof activates human GITR at an activation percentage greater than about 30%, greater than about 40%, greater than about 50%, greater than about 60%, or greater than about 65% at an EC_{50} of less than about 1.3 nM in the absence of Fc anchoring as determined by NFκB reporter assay, *e.g.*, as described in Example 5 or substantially similar assay format.

[0092] In some embodiments, the antibody or antigen-binding fragment thereof binds GITR and exhibits T-cell proliferative activity in the absence of Fc-anchoring as determined by naïve human CD4+ T-cell proliferation assay, *e.g.*, as described in Example 6 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment thereof binds GITR and exhibits T-cell proliferative activity in the absence of Fc anchoring with an EC_{50} of about 8 nM or less as determined by naïve human CD4+ T-cell proliferation assay, *e.g.*, as described in Example 6 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment thereof binds GITR and exhibits T-cell proliferative activity in the absence of Fc anchoring at least 2, at least 3, at least 4, at least 5, at least 6, at least 7, at least 8, at least 9, at least 10, or at least 11 fold above background at about 22 nM antibody (or antigen-binding fragment) concentration as determined by naïve human CD4+ T-cell proliferation assay, *e.g.*, as described in Example 6

or substantially similar assay format.

GITR activation in the presence of Fc anchoring

[0093] In some embodiments, the antibodies or antigen-binding fragments thereof provided herein activate human GITR in the presence of Fc anchoring, *e.g.*, as determined in the assay formats described in Example 5 and/or Example 6 herein, or in a substantially similar assay format. As used herein, "in the presence of Fc anchoring" refers to the activation of GITR and GITR mediated signaling or blocking of GITRL through the clustering of anti-GITR antibodies via the interaction of the Fc region of the antibodies with different forms of the Fc gamma receptor (FcgR), such as FcgRI, FcgRIIa or FcgRIIIa and can be determined and quantified via, *e.g.*, the activation of T-cells co-cultured *in vitro* in the presence of cell-surface bound Fc gamma receptor(s).

[0094] In some embodiments, the antibody or antigen-binding fragment thereof exhibits T-cell proliferative activity in the presence of Fc anchoring at least about 2 fold above background at about 33 nM antibody (or antibody-binding fragment) concentration as determined by naïve human CD4+ T-cell proliferation assay, *e.g.*, as described in Example 6 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment thereof exhibits T-cell proliferative activity in the presence of Fc anchoring at least about 2 fold, at least about 3 fold, at least about 4 fold, or at least about 5 fold above background at about 33 nM antibody (or antigen-binding fragment) concentration as determined by naïve human CD4+ T-cell proliferation assay, *e.g.*, as described in Example 6 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment exhibits T-cell proliferative activity in the presence of Fc anchoring with an EC_{50} of less than about 34 nM as determined by naïve human CD4+ T-cell proliferation assay, *e.g.*, as described in Example 6 or substantially similar assay format. In some embodiments, the antibody or antigen-binding fragment exhibits T-cell proliferative activity in the presence of Fc anchoring with an EC_{50} of less than about 30 nM, less than about 20 nM, less than about 10 nM, less than about 5 nM, or less than about 4 nM as determined by naïve human CD4+ T-cell proliferation assay, *e.g.*, as described in Example 6 or substantially similar assay format.

Antibodies that block GITR ligand mediated receptor stimulation

[0095] The present disclosure includes antibodies that block human GITR ligand (hGITRL)-mediated receptor stimulation, *e.g.*, as determined in the assay format described in Example 5 herein. As used herein, "blocks human GITR ligand (hGITRL)-mediated receptor stimulation" refers to the ability of anti-GITR antigen binding proteins to block the binding of GITR to its cognate ligand, GITRL. The blocking of GITR ligand can restore the suppression of effector T-cell activity by regulatory T cells. The blocking of GITR ligand can

be determined and quantified via a variety of methods known in the art, including, for example, the reduction in T-cell proliferation or cytokine secretion and an increase in the levels of circulating regulatory T cells.

[0096] In some embodiments, the antibodies provided herein block human GITR ligand (hGITRL)-mediated receptor stimulation in the absence of GITR anchoring, *e.g.*, as determined in the assay format described in Example 5 herein. In some embodiments, the antibody or antibody-binding fragment thereof blocks human GITR ligand-mediated receptor stimulation in the absence of Fc anchoring with a blocking percentage greater than about 55% at an IC_{50} less than about 4.0 nM as determined by NFκB reporter assay, *e.g.*, as described in Example 5 or substantially similar assay format. In some embodiments, the antibody or antibody-binding fragment thereof blocks human GITR ligand-mediated receptor stimulation in the absence of Fc anchoring with a blocking percentage greater than about 60%, greater than about 70%, greater than about 80%, or greater than about 85% at an IC_{50} less than about 4.0 nM, less than about 3.0 nM, less than about 2.0 nM, less than about 1.0 nM, less than about 0.9 nM, less than about 0.8 nM, or less than about 0.7 nM as determined by NFκB reporter assay, *e.g.*, as described in Example 5 or substantially similar assay format.

[0097] In some embodiments, the antibodies or antigen binding fragments activates human GITR and blocks human GITR ligand-mediated receptor stimulation at a blocking **percentage less than about 25% in the absence of Fc anchoring as determined by NFκB** reporter assay, *e.g.*, in the assay described in Example 5 or substantially similar assay. In some embodiments, the antibodies or antigen binding fragments activates human GITR and blocks human GITR ligand-mediated receptor stimulation at a blocking percentage less than **about 54% in the absence of Fc anchoring as determined by NFκB reporter assay**, *e.g.*, in the assay described in Example 5 or substantially similar assay. In some embodiments, the antibodies or antigen binding fragments activates human GITR and blocks human GITR ligand-mediated receptor stimulation at a blocking percentage less than about 40%, less than about 30%, less than about 20%, less than about 10%, less than about 5%, or less than **about 1% in the absence of Fc anchoring as determined by NFκB reporter assay**, *e.g.*, in the assay described in Example 5 or substantially similar assay. In some embodiments, the antibodies or antigen binding fragments activates human GITR at an activation percentage of at least about 50% and does not block hGITRL-mediated receptor stimulation at a blocking percentage of greater than about 50% in the absence of Fc anchoring as **determined by NFκB reporter assay**, *e.g.*, in the assay described in Example 5 or substantially similar assay.

[0098] In some embodiments, the antibodies or antigen binding fragments both activate

human GITR and block human GITR ligand (hGITRL)-mediated receptor stimulation.

[0099] In some embodiments, the antibodies both activate human GITR and block human GITR ligand (hGITRL)-mediated receptor stimulation in the absence of Fc anchoring, *e.g.*, as determined in the assay format described in example 5 herein, or a substantially similar assay. In some embodiments,

(A) the antibody or antigen-binding fragment possesses at least one of the properties selected from the group consisting of:

i. activates human GITR in the absence of Fc anchoring at an activation percentage greater than about 25% at an EC_{50} less than about 3 nM as determined by NFκB reporter assay and

ii. activates human GITR in the absence of Fc anchoring with an EC_{50} of less than about 1.0 nM as determined by NFκB reporter assay; and

(B) the antibody or antigen-binding fragment blocks hGITRL-mediated receptor stimulation in the absence of Fc anchoring at a blocking percentage greater than about 54% at an IC_{50} of less than about 4.0 nM as determined by NFκB reporter assay.

[0100] In some embodiments,

(A) the antibody or antigen-binding fragment activates human GITR in the absence of Fc anchoring at an activation percentage greater than about 50% at an EC_{50} less than about 1.5 nM as determined by NFκB reporter assay; and

(B) the antibody or antigen-binding fragment blocks hGITRL-mediated receptor stimulation in the absence of Fc anchoring at a blocking percentage greater than about 54% at an IC_{50} of less than about 4.0 nM as determined by NFκB reporter assay; and

Epitope Mapping and Related Technologies

[0101] The epitope to which the antibodies of the present invention 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 of a GITR protein. Alternatively, the epitope may consist of a plurality of non-contiguous amino acids (or amino acid sequences) of GITR. In some embodiments, the epitope is located on or near the GITRL-binding domain of GITR. In other embodiments, the epitope is located outside of the GITRL-binding domain of GITR, *e.g.*, at a location on the surface of GITR at which an antibody, when bound to such an epitope, does not interfere with GITRL binding to GITR.

[0102] 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, *e.g.*, routine cross-blocking assay such as that described Antibodies, Harlow and Lane (Cold Spring Harbor Press, Cold Spring Harb., NY), alanine scanning mutational analysis, peptide blots analysis (Reineke, 2004, Methods Mol Biol 248:443-463), and peptide cleavage analysis. In addition, methods such as epitope excision, epitope extraction and chemical modification of antigens can be employed (Tomer, 2000, Protein Science 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 to allow hydrogen-deuterium exchange to occur at all residues except for the residues protected by the antibody (which remain deuterium-labeled). 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(2):252-259; Engen and Smith (2001) *Anal. Chem. 73*:256A-265A.

[0103] The present invention further includes anti-GITR antibodies that bind to the same epitope as any of the specific exemplary antibodies described herein (*e.g.* antibodies comprising any of the amino acid sequences as set forth in Table 1 herein). Likewise, the present invention also includes anti-GITR antibodies that compete for binding to GITR with any of the specific exemplary antibodies described herein (*e.g.* antibodies comprising any of the amino acid sequences as set forth in Table 1 herein).

[0104] One can easily determine whether an antibody binds to the same epitope as, or competes for binding with, a reference anti-GITR antibody by using routine methods known in the art and exemplified herein. For example, to determine if a test antibody binds to the same epitope as a reference anti-GITR antibody of the invention, the reference antibody is allowed to bind to a GITR protein. Next, the ability of a test antibody to bind to the GITR molecule is assessed. If the test antibody is able to bind to GITR following saturation binding with the reference anti-GITR antibody, it can be concluded that the test antibody binds to a different epitope than the reference anti-GITR antibody. On the other hand, if the test antibody is not able to bind to the GITR molecule following saturation binding with the reference anti-GITR antibody, then the test antibody may bind to the same epitope as the epitope bound by the reference anti-GITR antibody of the invention. 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, Biacore, flow cytometry or any other quantitative or qualitative antibody-binding assay available in the art. In accordance with certain embodiments of the present invention, two antibodies bind to the same (or overlapping) epitope if, *e.g.*, 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 are deemed to bind to 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 are deemed to have "overlapping epitopes" if only a subset of the amino acid mutations that reduce or eliminate binding of one antibody reduce or eliminate binding of the other.

[0105] To determine if an antibody competes for binding (or cross-competes for binding) with a reference anti-GITR antibody, the above-described binding methodology is performed in two orientations: In a first orientation, the reference antibody is allowed to bind to a GITR protein under saturating conditions followed by assessment of binding of the test antibody to the GITR molecule. In a second orientation, the test antibody is allowed to bind to a GITR molecule under saturating conditions followed by assessment of binding of the reference antibody to the GITR molecule. If, in both orientations, only the first (saturating) antibody is capable of binding to the GITR molecule, then it is concluded that the test antibody and the reference antibody compete for binding to GITR. 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 same epitope as the reference antibody, but may sterically block binding of the reference antibody by binding an overlapping or adjacent epitope.

Preparation of Human Antibodies

[0106] The anti-GITR antibodies of the present invention can be fully human antibodies. Methods for generating monoclonal antibodies, including fully human monoclonal antibodies 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 human GITR.

[0107] Using VELOCIMMUNE™ technology, for example, or any other similar known method for generating fully human monoclonal antibodies, high affinity chimeric antibodies to GITR are initially 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, ligand blocking activity, selectivity, epitope, etc. If necessary, mouse constant regions are replaced with a desired human constant region, for example wild-type or modified IgG1 or IgG4, to generate a fully human anti-GITR antibody. While the constant region selected may vary according to specific use, high affinity antigen-

binding and target specificity characteristics reside in the variable region. In certain instances, fully human anti-GITR antibodies are isolated directly from antigen-positive B cells.

Bioequivalents

[0108] The anti-GITR 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 human GITR. 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 anti-GITR 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 anti-GITR antibody or antibody fragment that is essentially bioequivalent to an anti-GITR antibody or antibody fragment of the invention. Examples of such variant amino acid and DNA sequences are discussed above.

[0109] 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 dose. 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.

[0110] In one embodiment, two antigen-binding proteins are bioequivalent if there are no clinically meaningful differences in their safety, purity, and potency.

[0111] 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.

[0112] 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.

[0113] Bioequivalence may be demonstrated by *in vivo* and *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.

[0114] Bioequivalent variants of anti-GITR 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 anti-GITR antibody variants comprising amino acid changes which modify the glycosylation characteristics of the antibodies, *e.g.*, mutations which eliminate or remove glycosylation.

Species Selectivity and Species Cross-Reactivity

[0115] The present invention, according to certain embodiments, provides anti-GITR antibodies that bind to human GITR but not to GITR from other species. The present invention also includes anti-GITR antibodies that bind to human GITR and to GITR from one or more non-human species. For example, the anti-GITR antibodies of the invention may bind to human GITR and may bind or not bind, as the case may be, to one or more of mouse, rat, guinea pig, hamster, gerbil, pig, cat, dog, rabbit, goat, sheep, cow, horse, camel, cynomologous, marmoset, rhesus or chimpanzee GITR. According to certain exemplary embodiments of the present invention, anti-GITR antibodies are provided which specifically bind human GITR and cynomolgus monkey (*e.g.*, *Macaca fascicularis*) GITR. Other anti-GITR antibodies of the invention bind human GITR but do not bind, or bind only weakly, to cynomolgus monkey GITR.

Multispecific Antibodies

[0116] The antibodies of the present invention may be monospecific or multispecific (*e.g.*, bispecific). Multispecific 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. The anti-GITR antibodies of the present invention can be linked to or co-expressed with another functional molecule, *e.g.*, another peptide or protein. For example, an antibody or fragment thereof can be functionally linked (*e.g.*, by chemical

coupling, genetic fusion, noncovalent association or otherwise) to one or more other molecular entities, such as another antibody or antibody fragment to produce a bispecific or a multispecific antibody with a second binding specificity.

[0117] The present invention includes bispecific antibodies wherein one arm of an immunoglobulin binds human GITR, and the other arm of the immunoglobulin is specific for a second antigen. The GITR-binding arm can comprise any of the HCVR/LCVR or CDR amino acid sequences as set forth in Table 1 herein. In certain embodiments, the GITR-binding arm binds human GITR and blocks GITRL binding to GITR. In other embodiments, the GITR-binding arm binds human GITR but does not block GITRL binding to GITR. In some embodiments, the GITR binding arm binds human GITR and activates GITR signaling. In other embodiments, the GITR binding arm blocks GITRL mediated receptor stimulation. The present invention also includes bispecific antibodies wherein one arm of an antibody binds a first epitope of human GITR, and the other arm of said antibody binds a second distinct epitope of human GITR.

[0118] An exemplary bispecific 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 bispecific antibody to Protein A as compared to a bispecific 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 bispecific antibody format described above are contemplated within the scope of the present invention.

[0119] 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 Mab^2 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 Formulation and Administration

[0120] The invention provides pharmaceutical compositions comprising the anti-GITR antibodies or antigen-binding fragments thereof of the present invention. The pharmaceutical compositions of the invention are formulated with suitable carriers, excipients, and other agents that 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™, Life Technologies, Carlsbad, CA), 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.

[0121] The dose of antibody administered to a patient may vary depending upon the age and the size of the patient, target disease, conditions, route of administration, and the like. The preferred dose is typically calculated according to body weight or body surface area. In an adult patient, it may be advantageous to intravenously administer the antibody of the present invention normally at a single dose of about 0.01 to about 20 mg/kg body weight, more preferably about 0.02 to about 7, about 0.03 to about 5, or about 0.05 to about 3 mg/kg body weight. Depending on the severity of the condition, the frequency and the duration of the treatment can be adjusted. Effective dosages and schedules for administering anti-GITR antibodies may be determined empirically; for example, patient progress can be monitored by periodic assessment, and the dose adjusted accordingly. Moreover, interspecies scaling of dosages can be performed using well-known methods in the art (*e.g.*, Mordenti *et al.*, 1991, *Pharmaceut. Res. 8*:1351).

[0122] 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, 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.

[0123] 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.

[0124] Numerous reusable pen and autoinjector delivery devices have applications in the subcutaneous delivery of a pharmaceutical composition of the present invention. Examples include, but are not limited to AUTOPEN™ (Owen Mumford, Inc., Woodstock, UK), DISETRONIC™ pen (Disetronic Medical Systems, Bergdorf, 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 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.

[0125] In certain situations, the pharmaceutical composition can be delivered in a controlled release system. In one embodiment, a pump may be used (see Langer, supra; Sefton, 1987, CRC Crit. Ref. Biomed. Eng. 14:201). In another embodiment, polymeric materials can be used; see, Medical Applications of Controlled Release, Langer and Wise (eds.), 1974, CRC Pres., Boca Raton, Florida. 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 (see, *e.g.*, Goodson, 1984, in Medical Applications of Controlled Release, supra, vol. 2, pp. 115-138). Other controlled release systems are discussed in the review by Langer, 1990, Science 249:1527-1533.

[0126] The injectable preparations may include dosage forms for intravenous, subcutaneous, intracutaneous 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.

[0127] 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 aforesaid 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 aforesaid antibody is contained in about 5 to about 100 mg and in about 10 to about 250 mg for the other dosage forms.

Therapeutic Uses of the Antibodies

[0128] The present invention includes methods comprising administering to a subject in need thereof a therapeutic composition comprising an anti-GITR antibody (*e.g.*, an anti-GITR antibody comprising any of the HCVR/LCVR or CDR sequences as set forth in Table 1 herein). The therapeutic composition can comprise any of the anti-GITR antibodies, antigen-binding fragments thereof, or ADCs disclosed herein, and a pharmaceutically acceptable carrier or diluent.

[0129] The antibodies of the invention are useful, *inter alia*, for the treatment, prevention and/or amelioration of any disease or disorder associated with or mediated by GITR expression or activity, or treatable by blocking the interaction between GITR and GITRL, and/or inhibiting or stimulating GITR activity and/or signaling. For example, the antibodies

and antigen-binding fragments of the present disclosure can be used to treat immune and proliferative diseases or disorders, *e.g.*, cancer, by modulating the immune response, though, *e.g.*, GITR activation.

[0130] The antibodies and antigen-binding fragments of the instant disclosure can be used to treat a disease or disorder by enhancing an immune response. The instant disclosure includes methods of modulating anti-tumor immune response in a subject comprising administering to the subject an anti-GITR antibody or antigen-binding fragment described herein. In certain embodiments, the antibody or antigen-binding fragment reduces the suppressive activity of T effector cells by T regulatory cells. In some embodiments, the antibody or antigen-binding fragment of the instant disclosure enhances intra-tumoral T effector/T regulatory cell ratio conducive for therapeutic benefit. In some embodiments, the antibody or antigen-binding fragment of the instant disclosure promotes T cell survival.

[0131] Exemplary diseases or disorders that can be treated by the antibodies and antigen-binding fragments include immune and proliferative diseases or disorders, *e.g.*, cancer. The antibodies and antigen-binding fragments of the present invention can be used to treat primary and/or metastatic tumors arising in the brain and meninges, oropharynx, lung and bronchial tree, gastrointestinal tract, male and female reproductive tract, muscle, bone, skin and appendages, connective tissue, spleen, immune system, blood forming cells and bone marrow, liver and urinary tract, and special sensory organs such as the eye. In some embodiments, the antibodies and antigen-binding fragments of the instant disclosure are used to treat solid or blood-borne tumors. In certain embodiments, the antibodies of the instant disclosure are used to treat one or more of the following cancers: renal cell carcinoma, pancreatic carcinoma, head and neck cancer, prostate cancer, malignant gliomas, osteosarcoma, colorectal cancer, gastric cancer (*e.g.*, gastric cancer with MET amplification), malignant mesothelioma, multiple myeloma, ovarian cancer, cervical cancer, small cell lung cancer, non-small cell lung cancer, synovial sarcoma, thyroid cancer, breast cancer, melanoma, testicular, kidney, esophageal cancer, uterine cancer, endometrial cancer, or liver cancer.

[0132] In certain embodiments, the antibodies of the invention are useful for treating an autoimmune disease, including but not limited to, alopecia areata, autoimmune hepatitis, celiac disease, Graves' disease, Guillain-Barre syndrome, Hashimoto's disease, hemolytic anemia, inflammatory bowel disease, inflammatory myopathies, multiple sclerosis, primary biliary cirrhosis, psoriasis, rheumatoid arthritis, scleroderma, Sjögren's syndrome, systemic lupus erthyematosus, vitiligo, autoimmune pancreatitis, autoimmune urticaria, autoimmune thrombocytopenic purpura, Crohn's disease, diabetes type I, eosinophilic fasciitis, eosinophilic enterogastritis, Goodpasture's syndrome, myasthenia gravis, psoriatic arthritis, rheumatic fever, ulcerative colitis, vasculitis and Wegener's granulomatosis.

[0133] In the context of the methods of treatment described herein, the anti-GITR antibody may be administered as a monotherapy (*i.e.*, as the only therapeutic agent) or in combination with one or more additional therapeutic agents (examples of which are described elsewhere herein).

Combination Therapies and Formulations

[0134] Provided herein are also combination therapies utilizing an anti-GITR antibody of the present disclosure and any additional therapeutic agent that may be advantageously combined with an antibody of the instant disclosure or antigen-binding fragment thereof.

[0135] The present invention includes compositions and therapeutic formulations comprising any of the anti-GITR antibodies described herein in combination with one or more additional therapeutically active components, and methods of treatment comprising administering such combinations to subjects in need thereof.

[0136] The antibodies of the present invention may be combined synergistically with one or more anti-cancer drugs or therapy used to treat cancer, including, for example, renal cell carcinoma, colorectal cancer, glioblastoma multiforme, squamous cell carcinoma of head and neck, non-small-cell lung cancer, colon cancer, ovarian cancer, adenocarcinoma, prostate cancer, glioma, and melanoma. It is contemplated herein to use anti-GITR antibodies of the invention in combination with immunostimulatory and/or immunosupportive therapies to inhibit tumor growth, and/or enhance survival of cancer patients. The immunostimulatory therapies include direct immunostimulatory therapies to augment immune cell activity by either “releasing the brake” on suppressed immune cells or “stepping on the gas” to activate an immune response. Examples include targeting other checkpoint receptors, vaccination and adjuvants. The immunosupportive modalities may increase antigenicity of the tumor by promoting immunogenic cell death, inflammation or have other indirect effects that promote an anti-tumor immune response. Examples include radiation, chemotherapy, anti-angiogenic agents, and surgery.

[0137] The instant disclosure includes methods of modulating anti-tumor immune response in a subject comprising administering to the subject an anti-GITR antibody in combination with one or more agonistic antibodies against activating receptors and one or more blocking antibodies against inhibitory receptors that enhance T-cell stimulation to promote tumor destruction.

[0138] The instant disclosure includes methods of modulating anti-tumor immune response in a subject comprising administering to the subject an anti-GITR antibody or antigen-binding fragment described herein in combination with one or more isolated antibody or antigen-binding fragment thereof that binds to a second T-cell activating receptor (*i.e.*, other than GITR). In some embodiments, the second T-cell activating receptor is CD28, OX40, CD137,

CD27, or VEM. The instant disclosure also includes formulations comprising an anti-GITR antibody or antigen binding fragment thereof provided herein and an antibody or antigen-binding fragment that binds said second T-cell activating receptor.

[0139] In various embodiments, one or more antibodies of the present invention may be used in combination with an antibody to PD-L1, an antibody to PD-1 (*e.g.*, nivolumab), a LAG-3 inhibitor, a CTLA-4 inhibitor (*e.g.*, ipilimumab), a TIM3 inhibitor, a BTLA inhibitor, a TIGIT inhibitor, a CD47 inhibitor, an antagonist of another T-cell co-inhibitor or ligand (e.g., an antibody to CD-28, 2B4, LY108, LAIR1, ICOS, CD160 or VISTA), an indoleamine-2,3-dioxygenase (IDO) inhibitor, a vascular endothelial growth factor (VEGF) antagonist [*e.g.,* a "VEGF-Trap" such as aflibercept or other VEGF-inhibiting fusion protein as set forth in US 7,087,411, or an anti-VEGF antibody or antigen binding fragment thereof (*e.g.*, bevacizumab, or ranibizumab) or a small molecule kinase inhibitor of VEGF receptor (*e.g.*, sunitinib, sorafenib, or pazopanib)], an Ang2 inhibitor (*e.g.*, nesvacumab), a transforming growth factor beta (TGFβ) inhibitor, an epidermal growth factor receptor (EGFR) inhibitor (*e.g.*, erlotinib, cetuximab), an agonist to a co-stimulatory receptor (*e.g.*, an agonist to glucocorticoid-induced TNFR-related protein), an antibody to a tumor-specific antigen (*e.g.,* CA9, CA125, melanoma-associated antigen 3 (MAGE3), carcinoembryonic antigen (CEA), vimentin, tumor-M2-PK, prostate-specific antigen (PSA), mucin-1, MART-1, and CA19-9), a vaccine (*e.g.*, Bacillus Calmette-Guerin, a cancer vaccine), an adjuvant to increase antigen presentation (*e.g.*, granulocyte-macrophage colony-stimulating factor), a bispecific antibody (*e.g.*, CD3xCD20 bispecific antibody, PSMAxCD3 bispecific antibody), a cytotoxin, a chemotherapeutic agent (*e.g.*, dacarbazine, temozolomide, cyclophosphamide, docetaxel, doxorubicin, daunorubicin, cisplatin, carboplatin, gemcitabine, methotrexate, mitoxantrone, oxaliplatin, paclitaxel, and vincristine), cyclophosphamide, radiotherapy, an IL-6R inhibitor (*e.g.*, sarilumab), an IL-4R inhibitor (*e.g.*, dupilumab), an IL-10 inhibitor, a cytokine such as IL-2, IL-7, IL-21, and IL-15, an antibody-drug conjugate (ADC) (*e.g.*, anti-CD19-DM4 ADC, and anti-DS6-DM4 ADC), an anti-inflammatory drug (*e.g.*, corticosteroids, and non-steroidal anti-inflammatory drugs), a dietary supplement such as anti-oxidants or any palliative care to treat cancer. In certain embodiments, the anti-GITR antibodies of the present invention may be used in combination with cancer vaccines including dendritic cell vaccines, oncolytic viruses, tumor cell vaccines, etc. to augment the anti-tumor response. Examples of cancer vaccines that can be used in combination with anti-GITR antibodies of the present invention include MAGE3 vaccine for melanoma and bladder cancer, MUC1 vaccine for breast cancer, EGFRv3 (*e.g.*, Rindopepimut) for brain cancer (including glioblastoma multiforme), or ALVAC-CEA (for CEA+ cancers).

[0140] In some embodiments, one or more anti-GITR antibodies described herein are administered in combination with one or more anti-PD1 antibodies, including but not limited

to those described in U.S. Patent Publication No. 2015/0203579, which is incorporated herein by reference in its entirety. In some embodiments, the anti-GITR antibody is H1H14536P2 or H2aM14536P2. In some embodiments, the anti-PD1 antibody is REGN 2810 (also known as H4H7798N as disclosed in U.S. Patent Publication No. 2015/0203579), pembrolizumab, or nivolumab..

[0141] In certain embodiments, the anti-GITR antibodies of the invention may be administered in combination with radiation therapy in methods to generate long-term durable anti-tumor responses and/or enhance survival of patients with cancer. In some embodiments, the anti-GITR antibodies of the invention may be administered prior to, concomitantly or after administering radiation therapy to a cancer patient. For example, radiation therapy may be administered in one or more doses to tumor lesions followed by administration of one or more doses of anti-GITR antibodies of the invention. In some embodiments, radiation therapy may be administered locally to a tumor lesion to enhance the local immunogenicity of a patient's tumor (adjuvinating radiation) and/or to kill tumor cells (ablative radiation) followed by systemic administration of an anti-GITR antibody of the invention. For example, intracranial radiation may be administered to a patient with brain cancer (*e.g.*, glioblastoma multiforme) in combination with systemic administration of an anti-GITR antibody of the invention. In certain embodiments, the anti-GITR antibodies of the invention may be administered in combination with radiation therapy and a chemotherapeutic agent (*e.g.*, temozolomide) or a VEGF antagonist (*e.g.*, aflibercept).

[0142] In certain embodiments, the anti-GITR antibodies of the invention may be administered in combination with one or more anti-viral drugs to treat chronic viral infection caused by LCMV, HIV, HPV, HBV or HCV. Examples of anti-viral drugs include, but are not limited to, zidovudine, lamivudine, abacavir, ribavirin, lopinavir, efavirenz, cobicistat, tenofovir, rilpivirine and corticosteroids. In some embodiments, the anti-GITR antibodies of the invention may be administered in combination with a LAG3 inhibitor, a CTLA-4 inhibitor or any antagonist of another T-cell co-inhibitor to treat chronic viral infection.

[0143] In certain embodiments, the anti-GITR antibodies of the invention may be combined with an antibody to a Fc receptor on immune cells for the treatment of an autoimmune disease. In one embodiment, an antibody or fragment thereof of the invention is administered in combination with an antibody or antigen-binding protein targeted to an antigen specific to autoimmune tissue. In certain embodiments, an antibody or antigen-binding fragment thereof of the invention is administered in combination with an antibody or antigen-binding protein targeted to a T-cell receptor or a B-cell receptor, including but not limited to, Fcα (e.g., CD89), Fc gamma (e.g., CD64, CD32, CD16a, and CD16b), CD19, etc. The antibodies of fragments thereof of the invention may be used in combination with any drug or therapy known in the art (e.g., corticosteroids and other immunosuppressants) to

treat an autoimmune disease or disorder including, but not limited to alopecia areata, autoimmune hepatitis, celiac disease, Graves' disease, Guillain-Barre syndrome, Hashimoto's disease, hemolytic anemia, inflammatory bowel disease, inflammatory myopathies, multiple sclerosis, primary biliary cirrhosis, psoriasis, rheumatoid arthritis, scleroderma, Sjögren's syndrome, systemic lupus erthyematosus, vitiligo, autoimmune pancreatitis, autoimmune urticaria, autoimmune thrombocytopenic purpura, Crohn's disease, diabetes type I, eosinophilic fasciitis, eosinophilic enterogastritis, Goodpasture's syndrome, myasthenia gravis, psoriatic arthritis, rheumatic fever, ulcerative colitis, vasculitis and Wegener's granulomatosis.

[0144] The instant disclosure also includes methods of modulating anti-tumor immune response in a subject comprising administering to the subject an anti-GITR antibody or antigen-binding fragment described herein in combination with one or more isolated antibody or antigen-binding fragment thereof that binds to a T-cell inhibitory receptor. In some embodiments, the T-cell inhibitory receptor is CTLA-4, PD-1, TIM-3, BTLA, VISTA, or LAG-3. The instant disclosure also includes formulations comprising an anti-GITR antibody or antigen-binding fragment thereof provided herein and an antibody or antigen-binding fragment that binds said T-cell inhibitory receptor.

[0145] The instant disclosure also includes methods of treating cancer by administering an antibody or antigen-binding fragment thereof or formulation described herein to a subject in conjunction with radiation or chemotherapy.

[0146] In some embodiments, the anti-GITR antibodies of the present invention are co-formulated with and/or administered in combination with one or more additional therapeutically active component(s) selected from the group consisting of: an EGFR antagonist (*e.g.*, an anti-EGFR antibody [*e.g.*, cetuximab or panitumumab] or small molecule inhibitor of EGFR [*e.g.*, gefitinib or erlotinib]), an antagonist of another EGFR family member such as Her2/ErbB2, ErbB3 or ErbB4 (*e.g.*, anti-ErbB2 [*e.g.*, trastuzumab or T-DM1 {KADCYLA®}], anti-ErbB3 or anti-ErbB4 antibody or small molecule inhibitor of ErbB2, ErbB3 or ErbB4 activity), an antagonist of EGFRvIII (*e.g.*, an antibody that specifically binds EGFRvIII), a cMET anagonist (*e.g.*, an anti-cMET antibody), an IGF1R antagonist (*e.g.*, an anti-IGF1R antibody), a B-raf inhibitor (*e.g.*, vemurafenib, sorafenib, GDC-0879, PLX-4720), a PDGFR-α inhibitor (*e.g.*, an anti-PDGFR-α antibody), a PDGFR-β inhibitor (*e.g.*, an anti-PDGFR-β antibody or small molecule kinase inhibitor such as, *e.g.*, imatinib mesylate or sunitinib malate), a PDGF ligand inhibitor (*e.g.*, anti-PDGF-A, -B, -C, or -D antibody, aptamer, siRNA, etc.), a VEGF antagonist (*e.g.*, a VEGF-Trap such as aflibercept, *see*, *e.g.*, US 7,087,411 (also referred to herein as a "VEGF-inhibiting fusion protein"), anti-VEGF antibody (*e.g.*, bevacizumab), a small molecule kinase inhibitor of VEGF receptor (*e.g.*, sunitinib, sorafenib or pazopanib)), a DLL4 antagonist (*e.g.*, an anti-DLL4 antibody disclosed

in US 2009/0142354 such as REGN421), an Ang2 antagonist (*e.g.*, an anti-Ang2 antibody disclosed in US 2011/0027286 such as H1H685P), a FOLH1 antagonist (*e.g.*, an anti-FOLH1 antibody), a STEAP1 or STEAP2 antagonist (*e.g.*, an anti-STEAP1 antibody or an anti-STEAP2 antibody), a TMPRSS2 antagonist (*e.g.*, an anti-TMPRSS2 antibody), a MSLN antagonist (*e.g.*, an anti-MSLN antibody), a CA9 antagonist (*e.g.*, an anti-CA9 antibody), a uroplakin antagonist (*e.g.*, an anti-uroplakin [*e.g.*, anti-UPK3A] antibody), a MUC16 antagonist (*e.g.*, an anti-MUC16 antibody), a Tn antigen antagonist (*e.g.*, an anti-Tn antibody), a CLEC12A antagonist (*e.g.*, an anti- CLEC12A antibody), a TNFRSF17 antagonist (*e.g.*, an anti-TNFRSF17 antibody), a LGR5 antagonist (*e.g.*, an anti-LGR5 antibody), a monovalent CD20 antagonist (*e.g.*, a monovalent anti-CD20 antibody such as rituximab), etc. Other agents that may be beneficially administered in combination with antibodies of the invention include, *e.g.*, tamoxifen, aromatase inhibitors, and cytokine inhibitors, including small-molecule cytokine inhibitors and antibodies that bind to cytokines such as IL-1, IL-2, IL-3, IL-4, IL-5, IL-6, IL-8, IL-9, IL-11, IL-12, IL-13, IL-17, IL-18, or to their respective receptors.

[0147] The present invention includes compositions and therapeutic formulations comprising any of the anti-GITR antibodies described herein in combination with one or more chemotherapeutic agents. Examples of chemotherapeutic agents include alkylating agents such as thiotepa and cyclosphosphamide (Cytoxan™); alkyl sulfonates such as busulfan, improsulfan and piposulfan; aziridines such as benzodopa, carboquone, meturedopa, and uredopa; ethylenimines and methylamelamines including altretamine, triethylenemelamine, trietylenephosphoramide, triethylenethiophosphaoramide and trimethylolomelamine; nitrogen mustards such as chlorambucil, chlornaphazine, cholophosphamide, estramustine, ifosfamide, mechlorethamine, mechlorethamine oxide hydrochloride, melphalan, novembichin, phenesterine, prednimustine, trofosfamide, uracil mustard; nitrosureas such as carmustine, chlorozotocin, fotemustine, lomustine, nimustine, ranimustine; antibiotics such as aclacinomysins, actinomycin, authramycin, azaserine, bleomycins, cactinomycin, calicheamicin, carabicin, carminomycin, carzinophilin, chromomycins, dactinomycin, daunorubicin, detorubicin, 6-diazo-5-oxo-L-norleucine, doxorubicin, epirubicin, esorubicin, idarubicin, marcellomycin, mitomycins, mycophenolic acid, nogalamycin, olivomycins, peplomycin, potfiromycin, puromycin, quelamycin, rodorubicin, streptonigrin, streptozocin, tubercidin, ubenimex, zinostatin, zorubicin; anti-metabolites such as methotrexate and 5-fluorouracil (5-FU); folic acid analogues such as denopterin, methotrexate, pteropterin, trimetrexate; purine analogs such as fludarabine, 6-mercaptopurine, thiamiprine, thioguanine; pyrimidine analogs such as ancitabine, azacitidine, 6-azauridine, carmofur, cytarabine, dideoxyuridine, doxifluridine, enocitabine, floxuridine; androgens such as calusterone, dromostanolone propionate, epitiostanol,

mepitiostane, testolactone; anti-adrenals such as aminoglutethimide, mitotane, trilostane; folic acid replenisher such as frolinic acid; aceglatone; aldophosphamide glycoside; aminolevulinic acid; amsacrine; bestrabucil; bisantrene; edatraxate; defofamine; demecolcine; diaziquone; elfornithine; elliptinium acetate; etoglucid; gallium nitrate; hydroxyurea; lentinan; lonidamine; mitoguazone; mitoxantrone; mopidamol; nitracrine; pentostatin; phenamet; pirarubicin; podophyllinic acid; 2-ethylhydrazide; procarbazine; PSK™; razoxane; sizofiran; spirogermanium; tenuazonic acid; triaziquone; 2,2',2''-trichlorotriethylamine; urethan; vindesine; dacarbazine; mannomustine; mitobronitol; mitolactol; pipobroman; gacytosine; arabinoside ("Ara-C"); cyclophosphamide; thiotepa; taxanes, *e.g.* paclitaxel (Taxol™, Bristol-Myers Squibb Oncology, Princeton, N.J.) and docetaxel (Taxotere™; Aventis Antony, France); chlorambucil; gemcitabine; 6-thioguanine; mercaptopurine; methotrexate; platinum analogs such as cisplatin and carboplatin; vinblastine; platinum; etoposide (VP-16); ifosfamide; mitomycin C; mitoxantrone; vincristine; vinorelbine; navelbine; novantrone; teniposide; daunomycin; aminopterin; xeloda; ibandronate; CPT-11; topoisomerase inhibitor RFS 2000; difluoromethylornithine (DMFO); retinoic acid; esperamicins; capecitabine; and pharmaceutically acceptable salts, acids or derivatives of any of the above. Also included in this definition are anti-hormonal agents that act to regulate or inhibit hormone action on tumors such as anti-estrogens including for example tamoxifen, raloxifene, aromatase inhibiting 4(5)-imidazoles, 4-hydroxytamoxifen, trioxifene, keoxifene, LY 117018, onapristone, and toremifene (Fareston); and anti-androgens such as flutamide, nilutamide, bicalutamide, leuprolide, and goserelin; and pharmaceutically acceptable salts, acids or derivatives of any of the above.

[0148] The anti-GITR antibodies of the invention may also be administered and/or co-formulated in combination with antivirals, antibiotics, analgesics, corticosteroids, steroids, oxygen, antioxidants, COX inhibitors, cardioprotectants, metal chelators, IFN-gamma, and/or NSAIDs.

[0149] The additional therapeutically active component(s), *e.g.*, any of the agents listed above or derivatives thereof, may be administered just prior to, concurrent with, or shortly after the administration of an anti-GITR antibody of the present invention; (for purposes of the present disclosure, such administration regimens are considered the administration of an anti-GITR antibody "in combination with" an additional therapeutically active component). The present invention includes pharmaceutical compositions in which an anti-GITR antibody of the present invention is co-formulated with one or more of the additional therapeutically active component(s) as described elsewhere herein.

[0150] The additional therapeutically active component(s) may be administered to a subject prior to administration of an anti-GITR 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-GITR 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-GITR antibody of the present invention. "Concurrent" administration, for purposes of the present invention, includes, *e.g.*, administration of an anti-GITR antibody and an additional therapeutically active component to a subject in a single dosage form (*e.g.*, co-formulated), 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-GITR antibody and the additional therapeutically active component may be administered intravenously, subcutaneously, etc.); alternatively, each dosage form may be administered via a different route (*e.g.*, the anti-GITR antibody may be administered intravenously, and the additional therapeutically active component may be administered subcutaneously). In any event, administering the components in a single dosage from, 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-GITR 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-GITR antibody "in combination with" an additional therapeutically active component).

[0151] The present invention includes pharmaceutical compositions in which an anti-GITR antibody of the present invention is co-formulated with one or more of the additional therapeutically active component(s) as described elsewhere herein using a variety of dosage combinations.

[0152] In exemplary embodiments in which an anti-GITR antibody of the invention is administered in combination with a VEGF antagonist (*e.g.*, a VEGF trap such as aflibercept), including administration of co-formulations comprising an anti-GITR antibody and a VEGF

antagonist, the individual components may be administered to a subject and/or co-formulated using a variety of dosage combinations. For example, the anti-GITR antibody may be administered to a subject and/or contained in a co-formulation in an amount selected from the group consisting of 0.01 mg, 0.02 mg, 0.03 mg, 0.04 mg, 0.05 mg, 0.1 mg, 0.2 mg, 0.3 mg, 0.4 mg, 0.5 mg, 0.6 mg, 0.7 mg, 0.8 mg, 0.9 mg, 1.0 mg, 1.5 mg, 2.0 mg, 2.5 mg, 3.0 mg, 3.5 mg, 4.0 mg, 4.5 mg, 5.0 mg, 6.0 mg, 7.0 mg, 8.0 mg, 9.0 mg, and 10.0 mg; and the VEGF antagonist (*e.g.*, a VEGF trap such as aflibercept) may be administered to the subject and/or contained in a co-formulation in an amount selected from the group consisting of 0.1 mg, 0.2 mg, 0.3 mg, 0.4 mg, 0.5 mg, 0.6 mg, 0.7 mg, 0.8 mg, 0.9 mg, 1.0 mg, 1.1 mg, 1.2 mg, 1.3 mg, 1.4 mg, 1.5 mg, 1.6 mg, 1.7 mg, 1.8 mg, 1.9 mg, 2.0 mg, 2.1 mg, 2.2 mg, 2.3 mg, 2.4 mg, 2.5 mg, 2.6 mg, 2.7 mg, 2.8 mg, 2.9 mg and 3.0 mg. The combinations/co-formulations may be administered to a subject according to any of the administration regimens disclosed elsewhere herein, including, *e.g.*, twice a week, once every week, once every 2 weeks, once every 3 weeks, once every month, once every 2 months, once every 3 months, once every 4 months, once every 5 months, once every 6 months, etc.

Administration Regimens

[0153] According to certain embodiments of the present invention, multiple doses of an anti-GITR antibody (or a pharmaceutical composition comprising a combination of an anti-GITR 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-GITR antibody of the invention. As used herein, "sequentially administering" means that each dose of anti-GITR 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-GITR antibody, followed by one or more secondary doses of the anti-GITR antibody, and optionally followed by one or more tertiary doses of the anti-GITR antibody.

[0154] The terms "initial dose," "secondary doses," and "tertiary doses," refer to the temporal sequence of administration of the anti-GITR 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-GITR antibody, but generally may differ from one another in terms of frequency of administration. In certain embodiments, however, the amount of anti-

GITR 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").

[0155] In certain exemplary embodiments of the present invention, each secondary and/or tertiary dose is administered 1 to 26 (*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) weeks 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-GITR antibody which is administered to a patient prior to the administration of the very next dose in the sequence with no intervening doses.

[0156] 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-GITR 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. The administration regimen may be carried out indefinitely over the lifetime of a particular subject, or until such treatment is no longer therapeutically needed or advantageous.

[0157] In embodiments involving multiple secondary doses, each secondary dose may be administered at the same frequency as the other secondary doses. For example, each secondary dose may be administered to the patient 1 to 2 weeks or 1 to 2 months after the immediately preceding dose. Similarly, in embodiments involving multiple tertiary doses, each tertiary dose may be administered at the same frequency as the other tertiary doses. For example, each tertiary dose may be administered to the patient 2 to 12 weeks after the immediately preceding dose. 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.

[0158] The present invention includes administration regimens in which 2 to 6 loading doses are administered to a patient at a first frequency (*e.g.*, once a week, once every two weeks, once every three weeks, once a month, once every two months, etc.), followed by administration of two or more maintenance doses to the patient on a less frequent basis.

For example, according to this aspect of the invention, if the loading doses are administered at a frequency of once a month, then the maintenance doses may be administered to the patient once every six weeks, once every two months, once every three months, etc.

Diagnostic Uses of the Antibodies

[0159] The anti-GITR antibodies of the present invention may also be used to detect and/or measure GITR, or GITR-expressing cells in a sample, *e.g.*, for diagnostic purposes. For example, an anti-GITR antibody, or fragment thereof, may be used to diagnose a condition or disease characterized by aberrant expression (*e.g.*, over-expression, under-expression, lack of expression, etc.) of GITR. Exemplary diagnostic assays for GITR may comprise, *e.g.*, contacting a sample, obtained from a patient, with an anti-GITR antibody of the invention, wherein the anti-GITR antibody is labeled with a detectable label or reporter molecule. Alternatively, an unlabeled anti-GITR 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 ^{3}H, ^{14}C, ^{32}P, ^{35}S, or ^{125}I; a fluorescent or chemiluminescent moiety such as fluorescein, or rhodamine; or an enzyme such as alkaline phosphatase, beta-galactosidase, horseradish peroxidase, or luciferase. Specific exemplary assays that can be used to detect or measure GITR in a sample include enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA), immuno-PET (*e.g.*, ^{89}Zr, ^{64}Cu, etc.), and fluorescence-activated cell sorting (FACS).

[0160] Samples that can be used in GITR diagnostic assays according to the present invention include any tissue or fluid sample obtainable from a patient which contains detectable quantities of GITR protein, or fragments thereof, under normal or pathological conditions. Generally, levels of GITR in a particular sample obtained from a healthy patient (*e.g.*, a patient not afflicted with a disease or condition associated with abnormal GITR levels or activity) will be measured to initially establish a baseline, or standard, level of GITR. This baseline level of GITR can then be compared against the levels of GITR measured in samples obtained from individuals suspected of having a GITR related disease or condition.

EXAMPLES

[0161] 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, and pressure is at or near atmospheric.

Example 1. Generation of Anti-GITR Antibodies

[0162] Anti-GITR antibodies were obtained by immunizing a VELOCIMMUNE® mouse (*i.e.*, an engineered mouse comprising DNA encoding human immunoglobulin heavy and kappa light chain variable regions) with an immunogen comprising a soluble dimeric ecto domain of human GITR. The antibody immune response was monitored by a GITR-specific immunoassay. Several fully human anti-GITR antibodies were isolated directly from antigen-positive B cells without fusion to myeloma cells, as described in US 2007/0280945A1.

[0163] Certain biological properties of the exemplary anti-GITR 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 Nucleic Acid Sequences

[0164] Table 1 sets forth the amino acid sequence identifiers of the heavy and light chain variable regions and CDRs of selected anti-GITR antibodies of the invention. The corresponding nucleic acid sequence identifiers are set forth in Table 2.

Table 1: Amino Acid Sequence Identifiers

	SEQ ID NOs:							
Antibody Designation	HCVR	HCDR1	HCDR2	HCDR3	LCVR	LCDR1	LCDR2	LCDR3
H1H14474P	2	4	6	8	10	12	14	16
H1H14486P	18	20	22	24	26	28	30	32
H1H14491P	34	36	38	40	42	44	46	48
H1H14493P	50	52	54	56	58	60	62	64
H1H14495P	66	68	70	72	74	76	78	80
H1H14503P	82	84	86	88	90	92	94	96
H1H14512P	98	100	102	104	106	108	110	112
H1H14520P	114	116	118	120	122	124	126	128
H1H14523P	130	132	134	136	138	140	142	144
H1H14524P	146	148	150	152	154	156	158	160
H4H14469P	162	164	166	168	170	172	174	176
H4H14470P	178	180	182	184	186	188	190	192
H4H14475P	194	196	198	200	202	204	206	208
H4H14476P	210	212	214	216	218	220	222	224
H4H14508P	226	228	230	232	234	236	238	240
H4H14516P	242	244	246	248	250	252	254	256
H4H14521P	258	260	262	264	266	268	270	272
H4H14525P	274	276	278	280	282	284	286	288

H4H14528P	290	292	294	296	298	300	302	304
H4H14530P	306	308	310	312	314	316	318	320
H4H14531P2	322	324	326	328	402	404	406	408
H4H14532P2	330	332	334	336	402	404	406	408
H4H14536P2	338	340	342	344	402	404	406	408
H4H14539P2	346	348	350	352	402	404	406	408
H4H14541P2	354	356	358	360	402	404	406	408
H4H15736P2	362	364	366	368	402	404	406	408
H4H15740P2	370	372	374	376	402	404	406	408
H4H15744P2	378	380	382	384	402	404	406	408
H4H15745P2	386	388	390	392	402	404	406	408
H4H15753P2	394	396	398	400	402	404	406	408

Table 2: Nucleic Acid Sequence Identifiers

	SEQ ID NOs:							
Antibody Designation	**HCVR**	**HCDR1**	**HCDR2**	**HCDR3**	**LCVR**	**LCDR1**	**LCDR2**	**LCDR3**
H1H14474P	1	3	5	7	9	11	13	15
H1H14486P	17	19	21	23	25	27	29	31
H1H14491P	33	35	37	39	41	43	45	47
H1H14493P	49	51	53	55	57	59	61	63
H1H14495P	65	67	69	71	73	75	77	79
H1H14503P	81	83	85	87	89	91	93	95
H1H14512P	97	99	101	103	105	107	109	111
H1H14520P	113	115	117	119	121	123	125	127
H1H14523P	129	131	133	135	137	139	141	143
H1H14524P	145	147	149	151	153	155	157	159
H4H14469P	161	163	165	167	169	171	173	175
H4H14470P	177	179	181	183	185	187	189	191
H4H14475P	193	195	197	199	201	203	205	207
H4H14476P	209	211	213	215	217	219	221	223
H4H14508P	225	227	229	231	233	235	237	239
H4H14516P	241	243	245	247	249	251	253	255
H4H14521P	257	259	261	263	265	267	269	271
H4H14525P	273	275	277	279	281	283	285	287
H4H14528P	289	291	293	295	297	299	301	303
H4H14530P	305	307	309	311	313	315	317	319
H4H14531P2	321	323	325	327	401	403	405	407
H4H14532P2	329	331	333	335	401	403	405	407

H4H14536P2	337	339	341	343	401	403	405	407
H4H14539P2	345	347	349	351	401	403	405	407
H4H14541P2	353	355	357	359	401	403	405	407
H4H15736P2	361	363	365	367	401	403	405	407
H4H15740P2	369	371	373	375	401	403	405	407
H4H15744P2	377	379	381	383	401	403	405	407
H4H15745P2	385	387	389	391	401	403	405	407
H4H15753P2	393	395	397	399	401	403	405	407

[0165] Antibodies are typically referred to herein according to the following nomenclature: Fc prefix (*e.g.* "H1H," "H4H," etc.), followed by a numerical identifier (*e.g.* "14493," "14495," etc.), followed by a "P" or "P2" suffix, as shown in Tables 1 and 2. Thus, according to this nomenclature, an antibody may be referred to herein as, *e.g.*, " H1H14486P," " H4H14531P2," etc. The H1H, and H4H prefixes on the antibody designations used herein indicate the particular Fc region isotype of the antibody. For example, an "H1H" antibody has a human IgG1 Fc, an "H4H" antibody has a human IgG4 Fc, and an H2M has a mouse IgG2 Fc (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, but in any event, the variable domains (including the CDRs) – which are indicated by the numerical identifiers shown in Tables 1 and 2 – will remain the same, and the binding properties are expected to be identical or substantially similar regardless of the nature of the Fc domain.

Control Constructs Used in the Following Examples

[0166] Control constructs were included in the following experiments for comparative purposes: Anti-GITR Control Ab I: a mouse anti-human GITR hybridoma with variable heavy and light chain domains having the amino acid sequences of the corresponding domains of “clone 6C8” as set forth in WO 2006/ 105021 A2; produced with mIgG1 and mIgG2a constant regions in the following examples; and Anti-GITR Control Ab II: a human anti-GITR antibody with variable heavy and light chain domains having the amino acid sequences of the corresponding domains of “36E5” as set forth in US 8709424 B2.

Example 3. Surface Plasmon Resonance Derived Binding Affinities and Kinetic Constants of Human Monoclonal anti-TNFRSF18 (GITR) antibodies

[0167] Binding affinities and kinetic constants of human anti-GITR antibodies were determined by surface plasmon resonance (Biacore 4000 or T-200) at 37°C (Table 3). Antibodies, expressed as human IgG1 or IgG4 (i.e., “H1H” or “H4H” designations), were

captured onto a mouse anti-human Fc CM5 Biacore sensor surface (mAb-capture format) and soluble monomeric (human (h) GITR.mmh; SEQ ID NO: 409 and *Macaca fasicularis* (mf) GITR.mmh; SEQ ID NO: 412) or dimeric (hGITR.hFc; SEQ ID NO: 411 and hGITRmFc; SEQ ID NO: 410). GITR proteins were injected over the sensor surface at a flow rate of 30 µL/minute. All Biacore binding studies were performed in a buffer composed of 0.01M HEPES pH 7.4, 0.15M NaCl, 3mM EDTA, 0.05% v/v Surfactant P20 (HBS-ET running buffer). Antibody-reagent association was monitored for 4 minutes while dissociation in HBS-ET running buffer (10 mM HEPES, 150 mM NaCl, 3 mM EDTA, 0.05% (v/v) Surfactant P20, pH 7.4) was monitored for 10 minutes. 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 (t½) were calculated from the kinetic rate constants as: K_D [M] = k_d / k_a; and $t_{1/2}$ (min) = (ln2/(60*k_d). Results are summarized in Table 3.

Table 3: Biacore Binding Affinities of Human Fc mAbs at 37 ºC

	Binding at 37 °C/ Antibody Capture Format				
Antibody	**Analyte**	ka (Ms^{-1})	Kd (s^{-1})	K_D (Molar)	t½ (min)
H1H14503P	hGITR.mmh	5.32E+05	7.39E-04	1.39E-09	15.6
	hGITR.mFc	1.12E+06	1.54E-04	1.37E-10	75.0
	mfGITR.mmh	2.68E+05	5.60E-03	2.09E-08	2.1
H1H14474P	hGITR.mmh	5.91E+05	1.16E-03	1.96E-09	9.9
	hGITR.mFc	1.21E+06	1.30E-04	1.07E-10	89.2
	mfGITR.mmh	3.39E+05	9.51E-03	2.80E-08	1.2
H1H14495P	hGITR.mmh	5.17E+05	1.27E-03	2.45E-09	9.1
	hGITR.mFc	1.14E+06	1.10E-04	9.68E-11	105.0
	mfGITR.mmh	2.96E+05	7.23E-03	2.45E-08	1.6
H1H14486P	hGITR.mmh	4.39E+05	1.23E-03	2.79E-09	9.4
	hGITR.mFc	9.65E+05	1.53E-04	1.59E-10	75.5
	mfGITR.mmh	1.37E+05	1.66E-02	1.22E-07	0.7
H1H14524P	hGITR.mmh	4.05E+05	1.47E-03	3.62E-09	7.9
	hGITR.mFc	9.22E+05	1.35E-04	1.46E-10	85.6
	mfGITR.mmh	1.20E+05	1.89E-02	1.58E-07	0.6
H4H14530P	hGITR.mmh	2.72E+05	1.38E-03	5.06E-09	8.4
	hGITR.mFc	2.93E+05	1.85E-04	6.30E-10	62.6
	mfGITR.mmh	2.40E+05	6.11E-04	2.55E-09	18.9
H1H14491P	hGITR.mmh	3.19E+05	1.62E-03	5.06E-09	7.2
	hGITR.mFc	8.42E+05	1.69E-04	2.01E-10	68.3
	mfGITR.mmh	1.18E+05	8.89E-03	7.53E-08	1.3
H1H14523P	hGITR.mmh	2.16E+05	1.86E-03	8.63E-09	6.2
	hGITR.mFc	5.55E+05	1.20E-04	2.16E-10	96.3
	mfGITR.mmh	1.23E+05	1.09E-02	8.85E-08	1.1
H1H14493P	hGITR.mmh	1.86E+05	2.50E-03	1.34E-08	4.6
	hGITR.mFc	5.24E+05	1.91E-04	3.65E-10	60.4
	mfGITR.mmh	1.00E+04	1.40E-02	1.40E-06	0.8

	Binding at 37 °C/ Antibody Capture Format				
Antibody	**Analyte**	ka (Ms^{-1})	Kd (s^{-1})	K_D (Molar)	t½ (min)
H4H14532P2	hGITR.mmh	3.48E+05	6.45E-03	1.85E-08	1.8
	hGITR.mFc	7.20E+05	2.69E-04	3.73E-10	42.9
	mfGITR.mmh	2.60E+05	6.48E-03	2.49E-08	1.8
H4H14521P	hGITR.mmh	3.45E+05	7.84E-03	2.27E-08	1.5
	hGITR.mFc	1.23E+06	4.79E-04	3.89E-10	24.1
	mfGITR.mmh	1.66E+05	3.34E-03	2.01E-08	3.5
H4H14536P2	hGITR.mmh	4.24E+05	9.76E-03	2.30E-08	1.2
	hGITR.mFc	1.26E+06	2.19E-04	1.73E-10	52.7
	mfGITR.mmh	1.04E+05	1.47E-02	1.42E-07	0.8
H4H14476P	hGITR.mmh	3.92E+05	1.23E-02	3.14E-08	0.9
	hGITR.mFc	9.06E+05	2.69E-04	2.97E-10	42.9
	mfGITR.mmh	1.91E+05	1.07E-02	5.58E-08	1.1
H4H14516P	hGITR.mmh	2.25E+05	7.38E-03	3.27E-08	1.6
	hGITR.mFc	1.68E+06	1.81E-03	1.08E-09	6.4
	mfGITR.mmh	1.90E+05	1.12E-02	5.87E-08	1.0
H4H14508P	hGITR.mmh	2.55E+05	9.35E-03	3.66E-08	1.2
	hGITR.mFc	1.21E+06	7.19E-04	5.97E-10	16.1
	mfGITR.mmh	1.29E+05	5.07E-03	3.93E-08	2.3
H4H14469P	hGITR.mmh	2.84E+05	1.22E-02	4.30E-08	0.9
	hGITR.mFc	1.20E+06	4.01E-04	3.35E-10	28.8
	mfGITR.mmh	5.91E+04	2.43E-03	4.11E-08	4.7
H4H14475P	hGITR.mmh	3.07E+05	1.40E-02	4.57E-08	0.8
	hGITR.mFc	1.60E+06	1.35E-03	8.47E-10	8.5
	mfGITR.mmh	1.83E+05	7.65E-03	4.17E-08	1.5
H4H14528P	hGITR.mmh	1.02E+05	5.23E-03	5.13E-08	2.2
	hGITR.mFc	1.58E+06	1.77E-03	1.12E-09	6.5
	mfGITR.mmh	NB	NB	NB	NB
H4H14525P	hGITR.mmh	3.17E+05	1.66E-02	5.24E-08	0.7
	hGITR.mFc	7.91E+05	3.38E-04	4.27E-10	34.2
	mfGITR.mmh	1.33E+05	2.05E-02	1.55E-07	0.6
H1H14520P	hGITR.mmh	2.66E+05	1.67E-02	6.30E-08	0.7
	hGITR.mFc	1.09E+06	5.83E-04	5.37E-10	19.8
	mfGITR.mmh	1.99E+05	1.71E-02	8.59E-08	0.7
H4H14470P	hGITR.mmh	2.21E+05	1.43E-02	6.47E-08	0.8
	hGITR.mFc	9.04E+05	1.04E-03	1.15E-09	11.1
	mfGITR.mmh	NB	NB	NB	NB
H4H14539P2	hGITR.mmh	2.14E+05	1.77E-02	8.25E-08	0.7
	hGITR.mFc	8.53E+05	4.72E-04	5.54E-10	24.5
	mfGITR.mmh	7.23E+04	1.65E-03	2.28E-08	7.0
Anti-GITR Control Ab I-mIgG1	hGITR.mmh	2.16E+05	2.63E-02	1.22E-07	0.4
	hGITR.hFc	3.82E+05	7.80E-03	2.04E-08	1.5
	mfGITR.mmh	2.18E+05	4.64E-02	2.13E-07	0.2
Anti-GITR Control Ab II-hIgG1	hGITR.mmh	1.94E+05	9.67E-04	4.99E-09	11.9
	hGITR.mFc	1.83E+06	1.73E-03	9.48E-10	6.7
	mfGITR.mmh	2.31E+05	8.63E-03	3.74E-08	1.3

NB= No binding observed under conditions used

[0168] As shown in Table 3, all the anti-GITR antibodies of this invention bound to human GITR, with several antibodies displaying sub-nanomolar affinities to dimeric human GITR protein. Additionally, a majority of the anti-GITR antibodies also displayed cross reactivity to cynomolgus GITR protein. Cross reactivity to rodent GITR proteins was not observed (data not shown).

Example 4. Anti-GITR antibodies bind specifically and potently to human GITR expressing cells

[0169] In this example, the ability of anti-GITR antibodies to bind specifically to a human GITR-expressing cell line was determined using electrochemiluminescence (ECL) based detection.

[0170] Briefly, human embryonic kidney (HEK)-293-D9 cells were stably transfected with human GITR (amino acids M1-V241, NCBI Accession #NP_004186.1, SEQ ID: 413) via Lipofectamine 2000-mediated methodology. Transfectants were selected for at least two weeks in complete growth media + G418.

[0171] For cell binding studies, approximately $1x10^5$ hGITR/HEK293-D9 or parental HEK293-D9 cells, which do not express human GITR, were seeded onto 96-well carbon electrode plates (MULTI-ARRAY, MSD) for 1 h at 37°C. Nonspecific binding sites were blocked with 2% BSA (w/v) + PBS for 1 h at room temperature (RT). Next, serial dilutions of anti-GITR antibodies, ranging from 1.7 pM to 100nM, were added to cells for 1 h at RT. Plates were then washed to remove unbound antibodies (AquaMax2000 plate washer, MSD Analytical Technologies) and plate-bound antibodies were detected with a SULFO-TAG™ conjugated anti-human kappa light chain IgG antibody (Jackson Immunoresearch) for 1 h at RT.

[0172] Following washes, luminescent signals were recorded with a SECTOR Imager 6000 (MSD) instrument. Direct binding signals (relative light units, RLU) were analyzed as a function of the antibody concentration and data were fitted with a sigmoidal (four-parameter logistic) dose-response model using GraphPad Prism™ software. The EC_{50} for binding hGITR/HEK293-D9 cells, defined as the concentration of antibody at which 50% of the maximal binding signal is detected, was determined to indicate binding potency of each antibody. The signal detected with 100nM antibody binding to the hGITR expressing cells versus parental cells was recorded as an indication of intensity and specificity of GITR binding. Results are summarized in Table 4.

[0173] As summarized in Table 4, most of the anti-GITR antibodies of this invention bound specifically to human GITR expressing cells versus parental HEK293 with EC_{50}s ranging from 210 pM to 85 nM. A majority of the antibodies bound to human GITR-expressing cells with sub-nanomolar EC_{50} values. The isotype control antibody did not display binding to

hGITR-expressing or parental cell lines.

Table 4: Anti-GITR antibody binding EC_{50} and binding intensity at 100 nM on human GITR expressing cells

	Binding to hGITR/HEK293-D9 cells	Binding to hGITR/HEK293-D9 cells (at 100nM)	Binding to HEK293-D9 Cells (at 100nM)
Antibody	EC50 (M)	Average Signal (RLU)	Average Signal (RLU)
H1H14474P	2.80E-10	6230	680
H1H14486P	4.30E-10	5830	280
H1H14491P	4.00E-10	6840	300
H1H14493P	3.00E-10	7220	790
H1H14495P	4.30E-10	6470	340
H1H14503P	2.10E-10	5880	330
H1H14512P	2.50E-10	4620	180
H1H14520P	2.40E-10	6450	1130
H1H14523P	4.00E-10	6350	530
H1H14524P	2.10E-10	5740	500
H4H14469P	2.30E-10	5230	260
H4H14470P	1.40E-09	8390	1580
H4H14475P	8.00E-09	7500	1580
H4H14476P	5.70E-10	8120	1770
H4H14508P	4.50E-10	6870	580
H4H14516P	7.00E-10	10330	2560
H4H14521P	4.30E-10	10080	600
H4H14525P	6.00E-10	8840	1490
H4H14528P	4.50E-10	7310	420
H4H14530P	8.50E-08	4200	520
H4H14532P2	4.30E-10	5740	300
H4H14536P2	3.60E-10	8960	330
H4H14539P2	3.00E-10	4910	300
Anti-GITR Control Ab II-hIgG1	2.60E-10	13750	10240
Isotype Control Ab-hIgG4	NB	750	650

[0174] In summary, this example demonstrates that the anti-GITR antibodies of this invention display specific and potent binding to human GITR-expressing cell lines.

Example 5. Anti-GITR antibodies are partial blockers and partial activators in NF-κB/Luciferase reporter assay in the presence or absence of Fc gamma R antibody anchoring

[0175] In this example, the ability of anti-GITR antibodies to activate hGITR or block hGITR ligand (hGITRL)-mediated receptor stimulation in the presence or absence of

antibody anchoring to Fc gamma receptors (Fc gamma Rs) was assessed via luciferase-based reporter assays.

[0176] Briefly, a Jurkat cell line with stable incorporation of hGITR and NF- κB-dependent luciferase reporter was engineered (hGITR/Jurkat/NF- κBLuc). The NF- κB Luciferase reporter was introduced into Jurkat Cells using the Cignal Lenti Reporter system (SABiosciences). Lentiviruses expressing hGITR were generated in HEK293/T17 utilizing the Lenti-X Lentiviral Expression System (Clontech). Jurkat/NF-κB-Luc cells were transduced with the hGITR-expressing lentivirus via polybrene-mediated transduction and selected in 500 ug/ml G418 for 2 weeks. For antibody anchoring studies, HEK293 cells were transduced with the Fc gamma RI-expressing lentivirus, as described above.

[0177] First, the activation and blocking properties of anti-hGITR antibodies in the absence of Fc gamma R anchoring (non-anchored bioassay format) was assessed. Approximately $4x10^4$ Jurkat/NF-κBLuc/hGITR cells were seeded overnight (ON) in PDL coated 96 well plates in OptiMEM + 0.5% FBS.

[0178] To determine antibody activation ability, cells were incubated for 6 h at 37°C with serially diluted anti hGITR antibodies or hGITRL with concentrations ranging from 0.5 pM to 100 nM. To assess antibody blocking of hGITRL mediated receptor stimulation, cells were pre-incubated for 30 min with serially diluted anti hGITR antibodies (0.5 pM to 100 nM) followed by a constant dose of 10nM hGITRL for 6 h.

[0179] Next, the activation and blocking properties of selected anti-hGITR antibodies in the presence of Fc gamma R anchoring (anchored bioassay format) was determined. Similar to the above, $2.5x10^4$Jurkat/NfκBLuc/hGITR cells were seeded in PDL coated 96 well plates in complete growth media.

[0180] To assess antibody activation, cells were pre-incubated for 1 h at 37°C with serially diluted anti-hGITR mAbs or hGITRL (0.5 pM to 100 nM). Then, $1x10^4$ hFc gamma R1/HEK293 cells were immediately added to the wells followed by a 6 h incubation. To assess blocking, hGITR/Jurkat/NfκBLuc cells were pre-incubated for 1h with serially diluted anti-hGITR antibodies (0.5 pM to 100 nM). $1x10^4$ hFcγR1/HEK293 cells were added to the wells followed by the addition of a constant dose of 10 nM hGITRL.

[0181] For both anchored and non-anchored bioassay formats, Luciferase activity was measured with One glow reagent (Promega) and relative light units (RLUs) were measured on a Victor luminometer (Perkin Elmer). The EC_{50}/IC_{50} values were determined from a four-parameter logistic equation over a 12-point response curve using GraphPad Prism. Results are summarized in Table 5 and Table 6. To determine % blocking, background RLU (relative light units) from untreated wells are subtracted from treated wells, and the percent blocking is calculated according to the following formula: [100 - (antibody RLU at max

dose/constant ligand dose RLU)]*100]. % activation is calculated according the following formula: (normalized mAb RLU/max GITR ligand response)*100; normalized mAb RLU is determined by subtracting the RLU from untreated wells from treated wells. Mean fold activation is calculated as: RLU at maximum Antibody dose/ background RLU from untreated wells.

Table 5: Blocking and activation properties of anti-GITR antibodies in the absence of Fc gamma R anchoring

Antibody	IC_{50} (nM)	% Blocking-	EC_{50} (nM)	% Activation
H4H14475P	ND	-2	1.0	70
H1H14491P	0.60	90	2.0	60
H4H14521P	3.80	60	0.4	50
H1H14503P	0.60	90	1.4	50
H4H14469P	0.70	90	2.3	50
H4H14516P	2.30	70	0.8	45
H1H14523P	0.90	70	2.5	40
H1H14524P	0.70	80	2.2	40
H4H14528P	3.40	90	1.1	30
H1H14495P	0.70	80	1.3	30
H1H14474P	0.80	80	1.2	30
H4H14508P	0.90	40	1.2	30
H4H14532P2	1.00	90	1.2	30
H1H14486P	1.10	50	1.2	30
H1H14493P	0.60	90	1.2	25
H1H14512P	0.70	100	1.2	20
H4H14525P	1.40	70	1.1	20
H4H14539P2	1.20	30	1.3	20
H4H14536P2	2.00	90	1.1	20
H4H14470P	0.90	80	1.2	20
H4H14476P	2.60	90	1.0	10
H1H14520P	0.90	80	1.1	10
Anti-GITR Control Ab l-mIgG1	0.10	54	1.02	25
Isotype Control- IgG1	NB	NB	NA	NA
Isotype Control- IgG4	NB	NB	NA	NA

NB= no blocking
NA = no activation

[0182] As summarized in the Table 5 above and Table 6 below, the antibodies tested displayed partial activating and partial-blocking properties in both the non-anchored and anchored bioassay formats. In the non-anchored format, antibodies mediated receptor

stimulation with EC_{50}s ranging from 0.4 nM to 2.5 nM. Several antibodies, such as H4H14475P and H4H14491P were potent activators of the GITR receptor displaying 70 and 60 percent activation respectively. A majority of the antibodies tested also displayed blocking of hGITRL mediated receptor stimulation, with IC_{50}s ranging from 0.6 nM to 3.8 nM. Several exemplary antibodies, such as H1H14512P and H4H14536P2 displayed potent blocking activity of 100% and 90% respectively. H4H14475P, the most potent activator, displayed the least activity in the blocking assay (percent blocking: -2%).

Table 6: Blocking and activation properties of anti-GITR antibodies in the presence of Fc gamma R anchoring

Antibody	IC_{50} (nM)	% Blocking	EC_{50} (nM)	Fold Activation over basal signal
H1H14512P	0.10	64	0.02	7.0
H4H14475P	0.20	43	0.04	8.0
H4H14536P2	0.20	73	0.01	5.0
Anti-GITR Control Ab I-mIgG1	0.20	60	0.10	6.0
Anti-GITR Control Ab I-mIgG2a	0.01	74	0.20	5.0
Anti-GITR Control Ab II-hIgG1	0.20	70	0.01	8.0

[0183] Selected antibodies tested in the Fc gamma R-anchoring bioassay format also displayed a range of activation and blocking properties. H4H14475P, the strongest activator in the non-anchored format also potently activated hGITR in the anchored bioassay with a fold activation of 8.0 above the basal signal. Strong blockers in the non-anchored blocking format, such as H1H14512P and H4H14536P2, also displayed potent blocking in the anchored assay (% Blocking: 60% and 70 %).

[0184] In summary, the results demonstrate that the anti-GITR antibodies of this invention display potent GITR activating properties as well as the ability to block GITRL mediated receptor stimulation in the absence of Fc gamma R anchoring in an engineered bioassay. Exemplary antibodies, such as H4H14775P and H4H1536P2 also maintain their activating and blocking properties, respectively, in the presence of Fc gamma R anchoring.

Example 6. Anti-GITR antibody H4H14536P2 demonstrates potent activity in a Naïve Human CD4+ T-cell proliferation assay in the presence and absence of Fc gamma R anchoring

[0185] As described above, anti-GITR antibodies were tested in an engineered bioassay for their ability to activate hGITR in the presence or absence of anchoring Fc gamma receptors (Fc gamma R). In this example, the effect of antibody anchoring on hGITR activation was assessed in a naïve human CD4+ T-cell proliferation primary bioassay. The human CD4+ T-cell system has the advantage that GITR copy number is at endogenous levels, whereas the engineered system utilizes cells with a higher GITR copy number.

[0186] First, anti-GITR antibodies were tested for CD4+ T-cell proliferative ability in the presence of plate-bound anti-CD3. Briefly, Human $CD4^+$ T cells were isolated from healthy donor leukopacks using Human $CD4^+$ T cell Enrichment Cocktail (Stemcell Technologies). Naïve T cells were further enriched by depletion of CD45RO+ cells by MACS (Miltenyi Biotech). Approximately $5x10^4$ T cells were plated onto 96-well U-bottomed polystyrene plates pre-coated with a suboptimal amount of the anti-CD3 mAb OKT3 (30 ng/mL) and titrated amounts of anti-GITR antibodies or controls. Three days after stimulation, tritiated thymidine (1 µCi per well, Perkin Elmer Health Sciences NET027001) was added to each microwell and pulsed for 18 hours. Cells were harvested onto filter plates (Unifilter-96 GF/C 6005174) using a Filtermate Harvester (Perkin Elmer Health Sciences D961962). Scintillation fluid (Perkin Elmer Health Sciences Microscint20 6013621) was added to filter plates and radioactive counts were measured using a plate reader (Perkin Elmer Health Sciences Topcount NXT). T-cell proliferation relative to control, given as the mean fold activation at 10.6 nM of antibody concentration, is presented in Table 7. In this assay format, 10.6 nM represented the point at which T-cell proliferation reached a plateau on the dose response curve.

Table 7: T-cell proliferative activity (Fold activation) of plate-bound anti-GITR antibodies at 10.6 nM in the presence of plate-bound anti-CD3 Ab

	Donor								Mean Fold Activation
Antibody	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
H4H14536P2	3	24	24	25	24	47	26	16	23
H4H14508P	10	4	4	7	4	11	3	2	5
H4H14525P	6	1	1	2	1	3	2	1	2
H4H14469P	3	12	12	15	12	17	11	11	12
H4H14532P2	2	6	6	12	6	19	7	2	8
H4H14470P	0	3	3	4	3	6	4	1	3
H4H14475P	0	2	2	2	2	12	1	0	3
H4H14528P	2	8	8	4	8	31	5	4	8
H4H14539P2	2	12	12	13	12	39	11	6	13
H4H14516P	1	4	4	12	4	14	4	1	5

	Donor								Mean Fold Activation
Antibody	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
H4H14521P	1	4	4	5	4	12	3	2	4
Anti-GITR Control Ab 1-mIgG1	6	23	23	40	23	66	25	11	27
Isotype Control	1	1	1	1	1	1	1	1	1

[0187] As the results in Table 7 show, the anti-GITR antibodies tested demonstrated T-cell proliferative ability when plate-bound in the presence of plate-bound anti-CD3. The Anti-GITR Control Ab I demonstrated proliferative activity 27-fold above the isotype control. The majority of the anti-GITR antibodies of this invention displayed activation 2-8 fold above the isotype control, with several exemplary antibodies, H4H14469P, H4H14539P2, and H4H14536P2 demonstrating activation 12, 13 and 23 fold above the control, respectively. In summary, the results demonstrate that the anti-GITR antibodies tested demonstrate T-cell proliferative activity in this classical format.

[0188] Next, additional assay formats were employed to test the ability of anti-GITR antibodies to activate T-cells in the presence or absence of cell-surface bound Fc gamma R.

[0189] To assess anti-GITR antibody ability to activate T cells in the presence of Fc gamma R1 anchoring, HEK293 cells were engineered to express the high affinity hFc gamma R1 receptor, as described above. HEK293/ Fc gamma RI cells were treated with 50 ug/mL Mitomycin C for 30 min at 37°C to inhibit proliferation. After subsequent washes to remove traces of Mitomycin C, cells were coated with 300 ng/mL anti-CD3 antibody OKT3 to stimulate T cell activation. HEK293/Fc gamma RI cells were co-cultured with human naïve CD4+ T cells in a 1:2 ratio and titrated amounts of anti-GITR antibodies or controls were added to the co-culture medium.

[0190] T cell proliferation was assessed by measurement of the levels of tritiated thymidine incorporation. 72 h after stimulation, tritiated thymidine (0.5µCi per well, Perkin Elmer Health Sciences) was added to each microwell for an additional 18 h at 37°C. Cells were harvested onto filter plates (Unifilter-96 GF/C 6005174) using a Filtermate Harvester (Perkin Elmer Health Sciences D961962). Scintillation fluid (Perkin Elmer Health Sciences Microscint20 6013621) was added to filter plates and radioactive counts were measured using a plate reader (Perkin Elmer Health Sciences Topcount NXT). T-cell proliferation relative to control, given as the mean fold activation at a 33 nM concentration of antibody is presented in Table 8. In this assay format, 33 nM represented the point at which T-cell proliferation reached a plateau on the dose response curve.

Table 8: T-cell proliferative activity (Fold activation) of anti-GITR antibodies at 33nM in the presence of Fc gamma R anchoring

Antibody	Donor					Mean Fold Activation
	1	2	3	4	5	
H4H14536P2	1.3	6.3	1.5	2.7	15.7	5.5
H4H14508P	1.0	0.7	1.1	1.8	1.3	1.2
H4H14525P	1.2	0.8	1.0	1.5	1.5	1.2
H4H14469P	0.70	1.0	0.9	1.5	1.5	1.1
H4H14532P2	0.80	0.9	1.0	1.7	2.1	1.3
H4H14470P	1.8	1.0	1.4	1.5	2.0	1.5
H4H14475P	1.0	1.3	1.3	1.6	1.5	1.3
H4H14528P	0.9	1.5	1.1	1.9	1.7	1.4
H4H14539P2	0.9	0.7	1.1	1.5	1.5	1.1
H4H14516P	1.2	0.9	1.2	1.3	1.1	1.1
H4H14521P	1.5	1.1	1.1	1.7	0.9	1.2
H4H14476P	0.6	0.20	0.8	0.8	0.1	0.5
Anti-GITR Control mAbs						
Control I-mIgG1	2.8	2.8	1.4	1.1	1.7	2.0
Control I-mIgG2a	1.1	0.1	1.0	1.0	1.2	1.3
Control II-hIgG1	0.1	0.6	1.3	0.2	1.2	0.7
Isotype Control-hIgG4	1.0	1.0	1.0	1.0	1.0	1.0

Table 9: T-cell proliferative activity (EC_{50}) of anti-GITR antibodies at 33nM in the presence of Fc gamma R anchoring

Antibody	Donor					Mean EC_{50} (nM)
	1	2	3	4	5	
H4H14536P2	1.2	0.5	1.3	11.2	1.6	3.2
Control I-mIgG1	37.2	NA	42.9	3.5	52.7	34.1

[0191] As the results in Table 8 summarize, several antibodies showed activation above controls with levels ranging from 1-2 fold. However, one exemplary antibody, H4H14536P2, demonstrated potent T-cell proliferation activity in the anchored setting. With a mean fold activation of 5.5, H4H14536P2 stimulated greater T-cell activation compared to the anti-GITR comparator antibodies (mean fold activation range: 0.7 -2.0). H4H14536P2 had a mean EC_{50} of T-cell proliferation of 3.2 nM compared with 34.1 nM for the most potent anti-GITR control Ab, Control I-mIgG (Table 9). Furthermore, in this assay format, H4H14475P, a potent activator in the engineered bioassay described above, demonstrated modest

proliferative activity in this primary bioassay setting.

[0192] Next, antibodies were tested for T-cell proliferation activity in the absence of Fc gamma R anchoring. Human CD4+ T cells were isolated as described above, and plated onto 96-well U-bottomed polystyrene plates pre-coated with 30 ng/mL of the anti-CD3 antibody, OKT3. Similar to above, titrated concentrations of anti-GITR antibodies or controls were added to the culture medium. T cell proliferation was measured by tritiated thymidine incorporation. T-cell proliferation observed in four donors at 22 nM antibody concentration is presented as the fold activation compared to isotype control in Table 10. The EC50 (nM) of H4H14536P2 is shown in Table 11.

[0193] As observed in the anchored assay format, H4H14536P2 again displayed potent T cell proliferative activity at 22 nM in the non-anchored format. H4H14536P2 activated T cells with a mean fold activation of 11.0 and an EC_{50} of 8.3 nM. In this assay format, control anti-GITR antibody I exhibited no T-cell proliferation capability.

Table 10: T-cell proliferative activity (Fold activation) of anti-GITR antibodies at 22 nM in the absence of Fc gamma R anchoring

	Donor				Mean Fold Activation
Antibody	**1**	**2**	**3**	**4**	
H4H14536P2	6.2	4.2	10.1	23.4	11.0
H4H14508P	0.7	0.9	0.9	1.4	1.0
H4H14525P	0.7	1.0	0.9	1.0	0.9
H4H14469P	0.9	0.8	1.0	0.9	0.9
H4H14532P2	0.7	0.8	1.0	1.1	0.9
H4H14470P	0.7	0.9	1.0	1.7	1.1
H4H14475P	0.7	1.1	0.8	0.8	0.9
H4H14528P	0.6	0.8	0.9	1.0	0.8
H4H14539P2	0.5	0.8	1.1	0.8	0.8
H4H14516P	0.7	1.2	1.0	0.9	0.9
H4H14521P	0.5	1.2	0.8	1.0	0.9
H4H14476P	0.7	0.9	0.9	0.8	0.8
Anti-GITR Control Ab					
Control I- mIgG1	0.7	0.8	1.0	1.0	0.9
Isotype Control	1.0	1.0	1.0	1.0	1.0

Table 11: EC50 (nM) of H4H14536P2

Donor:	**1**	**2**	**3**	**4**	**Average**
H4H14536P2 EC_{50} (nM):	12.2	6.4	9.0	5.7	8.3

[0194] In summary, this example demonstrates that one exemplary anti-GITR antibody,

H4H14536P2, displays potent T-cell proliferative activity in the presence and absence of hFc gamma R1 anchoring, while the anti-GITR comparative antibody Control I displayed no T-cell proliferative activity in the non-anchored setting. Thus, the ability of H4H14536P2 to activate T cells in the absence of hFc gamma R1 anchoring is a unique property, implying that the antibody may not have to compete with endogenous IgG binding to Fc gamma receptors *in vivo* to retain activity. This unique property of H4H14536P2 may confer an advantage in a therapeutic setting.

Example 7. Administration of anti-GITR antibodies in combination with anti-PD1 antibodies synergistically controls and eradicates tumors

[0195] As assessment of the effect of administering anti-GITR antibodies in combination with anti-PD1 antibodies on tumor growth was performed using the following methods. The results of the assessment are summarized below.

Tumor implantation, treatment regimen and growth measurement

[0196] MC38 colorectal cancer cells (obtained from ATCC) were implanted subcutaneously in C57BL/6 mice ($3x10^5$ cells/mouse) (defined as day 0). On day 6 (i.e., 6 days post tumor implantation), mice were segregated into 4 groups (5 mice per group) and each group was treated intra-peritoneally (IP) with: (1) rat IgG2a (2A3, Bio X cell, Cat.# BE0089) (isotype control) + rat IgG2b (LTF2, Bio X cell, Cat.# BE0090) (isotype control) (2) anti-GITR monoclonal antibody DTA1 (rat anti-mouse GITR, Bio X cell, Cat.# BE0063) + rat IgG2a (control) (3) anti-PD-1 monoclonal antibody RPM1-14 (rat anti-mouse PD-1, Bio X cell, Cat.# BE0146) + rat IgG2b (control) or (4) anti-GITR antibody DTA1+ anti-PD-1 antibody RPM1-14. Antibody injection(s) were then administrated again on day 13. Antibody treatments were dosed at 5 mg/kg of each antibody. Tumors were measured two dimensionally (length x width) and tumor volume was calculated (length x $width^2$ x 0.5). Mice were euthanized when the tumor reached a designated tumor end-point (tumor volume > $2000mm^3$ or tumor ulceration).

Tumor re-challenge assessment

[0197] Mice treated with the combination of anti-PD-1 antibody and anti-GITR antibody that remained tumor free for over 80 days were re-challenged with 3 x 10^5 of the syngeneic tumor (MC38) in the right flank and 2.5 x 10^5 of an allogeneic (B16F10.9) tumor cell line (melanoma cell line, ATCC) in the left flank. Tumors were monitored as described above.

Antibody depletion experiments

[0198] Mice injected with different depleting mAbs (anti-CD4, anti-CD8, anti-CD25,) starting at one day prior of tumor challenge and given at twice weekly for total eight doses, were treated with the combination therapy or the isotype control IgG. The depletion efficiency was confirmed by FACS analysis of peripheral blood samples.

Flow cytometry (FACS) analysis of intratumoral lymphocytes

[0199] Mice were treated as described above. Five days after antibody treatment, tumor and spleen were collected. Tumors were minced with scissors and dissociated to single cell suspension with Liberase TL/DNAse I mix. Spleens were dissociated with gentleMACS Octo Dissociator. Cells were stained with panels of FACS antibodies against mouse CD45, CD3, CD4, CD8, CD25 and FoxP3, as well as activation markers (PD1, GITR, Ki67, CD160, CTLA4, ICOS, TIM3, LAG3, KLRG1 and CD44). Cells were acquired on BD Fortessa X20 or LSR II and analyzed by FlowJo software.

Administration of anti-mouse GITR antibodies in combination with anti-mouse PD1 antibodies significantly induces tumor regression and provides long-term tumor remission in MC38 bearing mice

[0200] Using the methods described above, the efficacy of administering an anti-mouse GITR antibody (clone DTA-1, Bio X cell, Cat.# BE0063) in combination with an anti-mouse PD-1 antibody (clone RMP1-14, Bio X cell, Cat.# BE0146) in the control of subcutaneous MC38 tumors was assessed. As shown in Figure 1 and Tables 12 and 13, combination treatment of PD1 blockade and anti-GITR (DTA-1) antibody significantly induced tumor regression in MC38 tumor bearing mice, in comparison to anti-PD-1 or anti-GITR mAb alone or isotype control treated mice. Furthermore, mice treated with combination therapy showed long-term tumor remission, as 100% of the mice remained tumor free for over 120 days (Figure 2, Tables 14, 15).

Table 12. Average tumor volumes for each treatment group (mm^3 ± SEM) and tumor free mice following anti-GITR and/or anti-PD-1 Ab treatment

	Tumor Volume (mm3) **Mean** (SEM)					**Tumor Free mice**
Treatment Group	**Day 10**	**Day 13**	**Day 17**	**Day 19**	**Day 21**	**Day 21**
Isotype (Rat IgG2a + Rat IgG2b)	**196** (44)	**232** (46)	**802** (869)	NA	NA	0/5
Anti-PD1 + Rat IgG2b	**181** (37)	**259** (103)	**551** (199)	**880** (335)	**1550** (616)	0/5
Anti-GITR + Rat IgG2a	**172** (9)	**262** (72)	**407** (112)	**741**(269)	**882** (307)	0/5
Anti-GITR + Anti-PD1	**130** (29)	**41** (13)	**0** (0)	**0** (0)	**0** (0)	5/5

Table 13. Summary of tumor free mice of three independent experiments following anti-GITR and/or anti-PD1 Ab treatment

	Tumor Free mice
Treatment Group	**Day 21**
Isotype (Rat IgG2a + Rat IgG2b)	0/15
Anti-PD1 + Rat IgG2b	0/15
Anti-GITR + Rat IgG2a	1/15
Anti-GITR + Anti-PD1	10/15

Table 14. Survival Proportions (percentage)

Days	Isotype	Anti-PD-1	Anti-GITR	Anti-PD-1 + Anti-GITR
0	**100**	**100**	**100**	**100**
17	**80**			
21		**40**		
24	**0**		**60**	
26			**20**	
35		**20**		
52		**0**	**0**	
123				**100**

Administration of anti-mouse GITR antibodies in combination with anti-mouse PD1 antibodies induces tumor/antigen-specific immunologic memory response

[0201] To determine whether mice treated with the combined administration of anti-PD-1 and anti-GITR antibodies developed a tumor/antigen-specific memory response, survival tumor-free mice were re-challenged with 3×10^5 of syngeneic MC38 colon carcinoma cells in the right flank and 2.5×10^5 of allogeneic melanoma cell line B16F10.9 in the left flank. It was found that MC38 tumors did not grow in mice treated with the anti-PD1 antibody and anti-GITR antibody combination, while the same tumors grew in naive control mice (without any previous treatment) (Figure 3). In contrast, the allogeneic tumor (melanoma) did not grow in both groups, demonstrating that the combined administration of anti-PD-1 and anti GITR antibodies induced tumor-antigen specific immunologic memory response capable of controlling the second challenge with the same type of tumor.

Immune population study

[0202] Mice were treated with CD4, CD8 and CD25 depleting mAbs prior to anti-PD-1 antibody and anti-GITR antibody combination treatment. It was found that depletion of CD8+ cells fully abrogated the anti-tumoral effect (MC38 tumors), while depletion of CD4 or CD25 T cells showed partial inhibition (Figure 4, Table 15). Thus, the anti-tumor effect of the combination therapy in MC38 tumors appears predominantly dependent on CD8+ T cells.

[0203] The effect of anti-GITR and anti-PD1 combination treatment on tumor infiltrating lymphocytes (TILs) was assessed. It was found that the combination treatment induced a significant increase in the CD8/T*reg* ratio in comparison to mono-therapy treatment (anti-PD-1 or anti-GITR) or isotype control (Figure 5). The effect of the combination treatment on CD4/T*reg* ratio was found to be less pronounced. Anti-PD-1 and anti-GITR combination treatment decreased the percentage of intra-tumoral T*regs* while it increased the CD8 T cells (Figure 6). Further, anti-PD-1 treatment alone induced expansion of the T*reg* cell number, while the anti-PD-1/anti-GITR combination treatment significantly reduced it in comparison to the isotype control treated mice.

Table 15. Anti-tumor efficacy after CD4, CD8, or CD25 depletion

		Tumor size (mm^3) **Mean** (SEM)		
Immunotherapy	**Depletion Antibody**	**Day 8**	**Day 12**	**Day 16**
Isotype control	Isotype control	**55** (12)	**161** (60)	**555** (224)
	Anti-CD4	**48** (17)	**60** (22)	**135** (71)
	Anti-CD8	**49** (17)	**176** (431)	**825** (431)
	Anti-CD25	**59** (16)	**61** (21)	**182** (68)
Anti-GITR + Anti-PD1	Isotype control	**43** (19)	**26** (16)	**11** (7)
	Anti-CD4	**68** (21)	**50** (32)	**123** (122)
	Anti-CD8	**67** (23)	**222** (86)	**1041** (543)
	Anti-CD25	**14** (6)	**35** (30)	**80** (64)

Administration of anti-human GITR antibodies in combination with anti-mouse PD1 antibodies significantly induces tumor regression and provides long-term tumor remission in MC38 bearing GITR/GITRL humanized mice

[0204] The efficacy of administering an anti-human GITR antibody (H2aM14536P2) in combination with an anti-mouse PD-1 antibody (clone RMP1-14 Bio X cell, Cat.# BE0146) in the control of subcutaneous MC38 tumors was assessed in GITR/GITRL humanized mice. It

was found that anti-mouse PD-1 blockade synergized with the anti-human GITR antibody and significantly induced tumor regression (4/6 mice) in MC38 tumor bearing mice, in comparison to anti-PD1 (1/7) or anti-GITR (1/7) mAb alone or isotype control (0/7) treated mice, as shown in the average tumor growth curves (Figure 7, Table 16). Further, mice treated with the combination therapy showed long-term tumor remission, as over 60% of the mice remain tumor free at day 50, in comparison to 0% for the isotype control and 10% for the anti-PD-1 or the anti-GITR treatment groups (Figure 8, Table 16).

Anti-human GITR antibodies increase intra-tumoral CD8/T*reg* ratio

[0205] The effect of anti-human GITR antibodies on intra-tumoral and splenic T cell populations was assessed. Anti-human GITR antibodies H2aM14536P2 and H1H14536P2 were evaluated. It was found that both anti-human GITR antibody isotypes (mIg2a and hIgG1) induced a significant increase in the intra-tumoral CD8/T*reg* ratio (Figure 9). The same treatment had no effect on peripheral spleen T cell subsets. Human IgG1 and mouse IgG2a isotype IgG were used in the assay for controls.

Table 16. Anti-tumor efficacy mediated by anti-human GITR antibody and anti-mouse PD1 antibody treatment

	Tumor size (mm^3) Mean (SEM)				**Tumor Free Mice**
Treatment Group	**Day 9**	**Day 13**	**Day 16**	**Day 19**	**Day 51**
Isotype control	146 (26)	248 (53)	402 (97)	838 (205)	0/7 (0%)
Anti-mPD1	120 (23)	163 (50)	275 (103)	617 (257)	1/7 (14%)
H2aM14536P2	134 (28)	162 (51)	194 (51)	346 (87)	1/7 (14%)
H2aH14536P2 +Anti-PD-1	122 (18)	90 (54)	114 (88)	192 (165)	4/6 (67%)

Administration of anti-mouse GITR antibodies in combination with anti-human PD1 antibodies significantly induces tumor regression and provides long-term tumor remission in MC38 bearing PD1/PDL1 humanized mice

[0206] The efficacy of administering an anti-mouse GITR antibody (DTA-1) in combination with an anti-human PD-1 antibody (REGN2810, also known as H4H7798N as disclosed in US Patent Publication No. 2015/0203579) in the control of subcutaneous MC38 tumors was assessed in PD1/PDL1 humanized mice. It was found that anti-human PD-1 blockade synergized with the anti-mouse GITR antibody and induced tumor growth delay in MC38 tumor bearing mice, in comparison to anti PD1 or anti GITR mAb alone or isotype control treated mice as shown in the average tumor growth curves (Figure 10, Table 17). Further, mice treated with the combination therapy showed long-term tumor remission as over 40%

of the mice remained tumor free at day 45, in comparison to 0% for the isotype control, the anti-PD-1 or the anti-GITR treatment groups (Figure 11).

Table 17. Anti-tumor efficacy mediated by anti-mouse GITR + anti-human PD1 Ab treatment

	Tumor size (mm3) **Mean** (SEM)			
Treatment Group	**Day 13**	**Day 17**	**Day 20**	**Day 24**
Isotype control	**301** (38)	**742** (81)	**1392** (104)	**2790** (366)
Anti-PD1(REGN2810)	**184** (21)	**354** (143)	**589** (201)	**937** (324)
Anti-GITR	**362** (99)	**713** (360)	**1199** (563)	NA
Anti-GITR + Anti-PD-1	**212** (117)	**120** (60)	**127** (62)	**167** (98)

Example 8: RNA Extraction and Analysis

Single-cell sorting RNA-seq analysis

[0207] On day 8 and 11 post tumor challenge, single cell suspension of tumor was prepared by mouse tumor dissociation kit (Miltenyi Biotec, Bergisch Gladbach, DE) and spleens were dissociated with gentleMACS™ Octo Dissociator (Miltenyi Biotec). Tumors and spleens from the same treatment group were pooled and viable CD8+ T cells were sorted by FACS. FACS sorted T cells were mixed with C1 Cell Suspension Reagent (Fluidigm, South San Francisco, CA) before loading onto a 5- to 10-µm C1 Integrated Fluidic Circuit (IFC; Fluidigm). LIVE/DEAD staining solution was prepared by adding 2.5 µL ethidium homodimer-1 and 0.625 µL calcein AM (Life Technologies, Carlsbad, CA) to 1.25 mL C1 Cell Wash Buffer (Fluidigm) and 20 µL was loaded onto the C1 IFC. Each capture site was carefully examined under a Zeiss microscope in bright field, GFP, and Texas Red channels for cell doublets and viability. Cell lysing, reverse transcription, and cDNA amplification were performed on the C1 Single-Cell Auto Prep IFC, as specified by the manufacturer (protocol 100-7168 E1). The SMARTer™ Ultra Low RNA Kit (Clontech, Mountain View, CA) was used for cDNA synthesis from the single cells. Illumina NGS libraries were constructed using the NEXTERA XT DNA Sample Prep kit (Illumina), according to the manufacturer's recommendations (protocol 100-7168 E1). A total of 2,222 single cells were sequenced on Illumina NextSeq (Illumina, San Diego, CA) by multiplexed single-read run with 75 cycles. Raw sequence data (BCL files) were converted to FASTQ format via Illumina CASAVA 1.8.2. Reads were decoded based on their barcodes. Read quality was evaluated using FastQC (www.bioinformatics. babraham.ac.uk/projects/fastqc/).

Example 9: Role of CD226 and TIGIT in combination treatment

[0208] Genetic inactivation or pharmacological inhibition of CD226 reversed the tumor

regression mediated by anti-GITR / anti-PD1 combination treatment in some experiments, while inhibition of other TNF-receptor or B7 superfamily members had no effect.

CD226 Blocking experiment

[0209] 0.5 mg of anti-CD226 (10E5, eBioscience, San Diego, CA) or rat IgG2b isotype control IgG (LTF2, Bio X Cell, West Lebanon, NH) were injected intraperitoneally (i.p.) on day 5 post tumor challenge and one day prior to immunotherapy. Perpendicular tumor diameters were measured blindly 2-3 times per weeks using digital calipers (VWR, Radnor, PA). Volume was calculated using the formula L × W × 0.5, where L is the longest dimension and W is the perpendicular dimension. Differences in survival were determined for each group by the Kaplan-Meier method and the overall P value was calculated by the log-rank testing using survival analysis by PRISM version 6 (GraphPad Software Inc., La Jolla, CA). An event was defined as death when tumor burden reached the protocol-specified size of 2000 mm^3 in maximum tumor volume to minimize morbidity.

[0210] As shown in Figures 12 and 13, MC38 tumor bearing mice were treated with either CD226 blocking Ab or isotype Ab (control IgG) 1d prior to immunotherapy with anti-GITR + anti-PD-1 or isotype Abs. Average tumor growth curve (Fig. 12) and survival curves (Fig. 13) are shown. Data are representative of three experiments, n = 5 mice per group, survival analysis by Log-rank test.

[0211] Wild type or TIGIT KO mice were challenged with MC38 tumors, treated with anti-CD226 or control IgG and either received isotype control (Fig. 14) or anti-GITR+anti-PD-1 combination therapy (Fig. 15). Data shown are average tumor growth curves representative of two experiments (n = 4-5 mice per group).

[0212] Using the CD226 blocking mAb, it was shown that co-stimulatory signaling through CD226 is required for the anti-tumor immunity mediated by combination treatment. Furthermore, the CD226 signaling pathway was required for enhanced tumor surveillance in TIGIT KO mice (Figs. 14 and 15).

RNA signatures in CD8+ T cells from combination treatment samples

[0213] To identify unique gene signatures in clonally expanded $CD8^+$ T cells (tumors harvested at day 11) from combination treatment samples, comprehensive comparisons across different treatment groups were performed. Genes upregulated in clonally expanded CD8+ T cells from combination therapy were compared to upregulated genes of CD8+ T cells from isotype treatment or non-expanded CD8+ T cells with combination treatment. Heat mapping analysis identified thirty genes overlapping within the comparison. An RNA signature change of ≥ 2-fold ($p < 0.01$) was observed within the expanded CD8 T cell population for the 30 genes after the anti-GITR/anti-PD1 combination treatment of tumors. Those 30 genes include Id2, S100a11, Ndufb3, Serinc3, Ctsd, S100a4, Ppp1ca, Lbr, Peli1,

Lcp2, Ube2h, Cd226, Mapkapk3, Racgap1, Arf3, Mki67, Ergic2, Azi2, Dync1i2, Sik1, Pde4d, Ppp3cc, Nek7, Emc4, Vav1, Dock10, Tmem173, Fam3c, Ppp1cc, and Glud1.

[0214] A four-way comparison across all five groups (*i.e.,* (i) isotype treatment, (ii) anti-GITR expanded CD8, (iii) anti-GITR/anti-PD1 combination expanded CD8, (iv) anti-PD1 expanded CD8, and (v) anti-GITR/anti-PD1 combination non-expanded CD8) was next performed to identify genes specifically regulated upon combination therapy versus monotherapy treatment. Two overlapping upregulated genes ($p < 0.01$, ≥ 2 fold change in expression) were identified in the four-way analysis. CD226, which is a costimulatory molecule that plays an important role in anti-tumor response, was identified as one of the two genes shared across different comparison pairs. Expression analysis of different subsets of intratumoral $CD8^+$ T cells ((a) total, (b) clonally expanded, or (c) non-expanded) across treatment groups (*i.e.,* (i) isotype, (ii) anti-GITR, (iii) anti-PD1, and (iv) anti-GITR/anti-PD1 combination) revealed that CD226 mRNA levels were significantly increased by combination treatment on clonally expanded T cells (fold change = 10.7), while this difference was diluted in bulk (fold change = 3.5) and non-expanded $CD8^+$ T cells (not significant). Further, CD226 mRNA levels were significantly increased by combination treatment on clonally expanded CD8 T cells in comparison to anti-PD-1 (fold change = 6.5) and anti-GITR (fold change = 9.2) (Fig. 16).

Association between PD1 and CD226

[0215] The potential association between PD1 and CD226 molecules was next investigated. To examine if CD226 is a target for desphosphorylation by the PD1-Shp2 complex, we reconstituted different components involved in T cell signaling in a cell-free large unilamellar vesicle (LUV) system (*i.e.,* CD3, CD226, cytosolic tyrosine kinase Lck, Zap70, SLP76 52, and PI3K (p85a). The sensitivity of each component in response to PD-1 titration on the LUVs was measured by phosphotyrosine (pY) immunoblotting (Fig. 17). We confirmed that TCR/CD3ζ was not a target of desphosphorylation by PD-1-Shp2, whereas CD226 was efficiently dephosphorylated by PD1-Shp2 in a dose dependent manner after 30 minutes of treatment (Fig. 17). This data demonstrated an association between PD-1 and CD226.

[0216] Next, the relationship between PD-1 inhibition and CD226 expression was investigated in a clinical setting. RNA-seq analysis was performed on tumor biopsies collected from 43 advanced cancer patients pre- and post-PD-1 targeted treatment. CD226 expression was significantly increased after two doses of anti-hPD-1 treatment in cancer patients (Fig. 22). Further, clinical data from The Cancer Genome Atlas (TCGA) was interrogated to examine if CD226 expression level correlates with the overall T cell activation strength and may be predictive of a better prognosis in cancer patients. Indeed, patients with

high baseline CD226 expression have significantly higher survival probabilities in five (skin cutaneous melanoma, lung adenocarcinoma, head and neck squamous carcinoma, uterine corpus endometrial carcinoma and sarcoma) out of twenty different types of cancer evaluated (skin cutaneous melanoma, lung adenocarcinoma, head and neck squamous carcinoma, uterine corpus endometrial carcinoma, sarcoma, rectum adenocarcinoma, breast invasive carcinoma, kidney renal clear cell carcinoma, cervical squamous cell carcinoma and endocervical adenocarcinoma, glioblastoma multiforme, colon adenocarcinoma, stomach adenocarcinoma, bladder urothelial carcinoma, thyroid carcinoma, prostate adenocarcinoma, pancreatic adenocarcinoma, brain lower grade glioma, lung squamous cell carcinoma, kidney renal papillary cell carcinoma, and ovarian serous cystadenocarcinoma. Overall, these results support an immunotherapy strategy that boosts CD226 signaling while simultaneously blocking TIGIT (*e.g.,* via anti-GITR treatment) for maximum T cell activation.

Genetic Inactivation of CD226

[0217] Using a CD226 blocking mAb, we showed that costimulatory signaling through CD226 was required for the anti-tumor immunity mediated by combination treatment (Figs. 12, 13). Since CD226 Ab could possibly have a potential depleting effect on subset of CD8 T cells, CD226 was genetically inactivated in C57BL/6 background mice to confirm that result. CD226-/- mice showed no defect on T cell (CD4+, CD8+, Tregs) homeostasis (Fig. 18, panels A-D) and responded similarly to wild-type mice to TCR activation (Fig. 18, panels E-I). We observed that the combination treatment no longer conferred the anti-tumor effect or survival benefit in CD226-/- mice, suggesting that CD226 was essential for the observed anti-tumor effects of the combination (Fig. 19, panel A). The effect of CD226 is specific, since the inhibition of other members of the TNF receptor superfamily (OX40L or 4-1BBL) or blockade of the B7 costimulatory molecule (CD28) using CTLA4-Ig preserved the anti-tumor effect mediated by the combination therapy (Fig. 19, panels B-D).

Requirement for CD226 in TIGIT Null Animals

[0218] Overall single-cell sorting RNA-seq and FACS phenotyping data showed that anti-PD-1 favored the expression of CD226, while anti-GITR treatment down-regulated surface expression of TIGIT, synergistically restoring the homeostatic T cell function.

[0219] We showed that the CD226 signaling pathway was required for enhanced tumor surveillance in TIGIT-/- mice (Figs. 14, 15). Additionally, mice bearing MC38 tumor cells overexpressing CD155/PVR6, which is the major ligand for CD226, showed significant delay of tumor growth upon anti-PD-1 or anti-GITR or combination therapy in comparison to MC38-empty vector (MC38-EV) tumor cells or mice treated with isotype control (Fig. 20). Immune profiling analysis of mice transplanted with MC38-CD155 confirmed sustained higher CD155 expression level on MC38-CD155 cells over M38-EV (empty vector) post-

implantation. We found that CD155 over-expression on MC38 tumor cells was associated with decreased detectable CD226 expression on CD4+, CD8+ T and T*regs* cells (Fig. 21A) , while it boosted T cell activation as indicated by enhanced IFNγ (Fig. 21B) and 4-1BB (Fig. 21C) expression on intra-tumoral T cells. No effect was observed in the periphery.

[0220] Without being bound by any theory, it is hypothesized that CD226 expression level should correlate with the overall T cell activation strength and may be predictive of a better prognosis in cancer patients. Indeed, patients with high CD226 expression have significantly higher survival probabilities in three types of cancer (skin cutaneous melanoma, lung adenocarcinoma and sarcoma). These data support an immunotherapy strategy that boosts CD226 signaling while simultaneously blocking TIGIT for maximum T cell activation.

[0221] The forgoing experiments demonstrate the synergistic effect of administering an anti-GITR antibody in combination with an anti-PD1 antibody. In particular, among other things, the experiments above demonstrate that the combined administration of an anti-GITR antibody and anti-PD1 antibody induces tumor regression, provides long-term tumor remission, and induces tumor/antigen-specific immunologic memory response.

Example 10: TCR Analysis

[0222] For TCR analysis, we developed a new bioinformatic pipeline rpsTCR for reconstructing and extracting TCR sequences, especially TCR-CDR3 sequences from random priming short RNA sequencing reads. The rpsTCR took paired- and single-end short reads and maps these reads to mouse or human genomes and transcriptomes, but not TCR gene loci and transcripts using TopHat (*Bioinformatics* 25, 1105–1111 (2009)) with default parameters. Mapped reads were discarded and unmapped reads are recycled for extraction of TCR sequences. Low quality nucleotides in the unmapped reads were trimmed. Then reads with length less than 35bp were filtered out using HTQC toolkit (*Bioinformatics* 14, 33 (2013). QC passed short reads was assembled into longer reads using iSSAKE (*Bioinformatics* 25, 458–464 (2009)) default setting. TCRklass (*J Immunol* 194, 446–454 (2015)) was used to identify CDR3 sequences with Scr (conserved residue support score) set from default 1.7 to 2. A targeted TCR-seq data from a healthy human PBMC samples was used as a positive control to evaluate whether the extra steps introduced to the pipeline resulted in higher false positive or false negative rates comparing to TCRklass alone.

[0223] The majority of unique CDR3 sequences from TCRB (64,031) or TCRA (51,448) were detected by both rpsTCR and TCRklass. The squared correlations between rpsTCR and TCRklass were 0.9999 and 0.9365 for TCRB-CDR3 and TCRA-CDR3, respectively. Six TCR-negative cancer or non-cancer cell lines were used as negative controls. No CDR3 sequences were detected by rpsTCR, whereas some CDR sequences were extracted by TCRklass from some TCR-negative cancer cell lines.

[0224] To further validate the performance of the subject pipeline, we sequenced a heathy mouse PBMC sample using both targeted TCR-seq and random priming RNA-seq approaches (200M, 2x100bp). Although the number of CDR3 sequences assembled from RNA-seq data was much smaller than that from the targeted TCR-seq approach, about 45% of the CDR3 sequences identified from RNA-seq data using rpsTCR were also observed among CDR3 sequences from targeted TCR-seq. Because of the technique limitation of targeted TCR-seq, it is not surprising that a fraction of the CDR3 sequences we extracted from RNA-seq data were not present in the TCR-seq results. For example, the efficiency of 5' race adapter used for targeted TCR-seq is generally low and the multiply PCR tends to amplify high frequency TCRs, thus only a small portion of TCRs can be targeted. As expected, much higher percentage (~ 70%) of the CDR3 sequences identified from RNA-seq data using rpsTCR were also observed among high frequency CDR3 sequences (>= 0.1%) from targeted TCR-seq, while only about 40% extracted using TCRklass alone. Moreover, we cut the 100bp read length in 50bp segments and randomly selected 200M reads. Among the top 10 CDR3 sequences ranked by targeted TCR-seq approach, 8 CDR3 sequences were detected by our rpsTCR, while only 3 were detected by TCRklass. We then applied our rpsTCR pipeline to extracting CDR3 sequences from the single cell RNA-seq data generated from intratumoral CD8 T cells of MC38 treated with different antibodies. Our CDR3_beta and CDR3_alpha sequence detection rates were comparable to published data using targeted TCR-seq approach to detect TCR sequences from single cell sequencing of T cells

[0225] 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.