# METHODS OF TREATING AUTOIMMUNE DISEASES WITH DLL4 ANTAGONISTS

## BACKGROUND OF THE INVENTION

### Field of the Invention

**[0001]** This invention relates to methods of treating a disease, disorder, or condition, in which increasing the number of regulatory T cells (Treg cells or Tregs) is beneficial, using delta-like ligand 4 (Dll4) antagonists. More specifically, the methods of the invention can treat various autoimmune diseases, such as multiple sclerosis and diabetes, as well as organ transplant rejections and graft-versus-host diseases (GVHD) by blocking the binding of Dll4 to a Notch receptor with Dll4 antagonists, thereby increasing the number of Tregs. The invention further relates to methods of preventing such diseases or disorders from occurring or recurring in a subject who is predisposed or susceptible to the diseases or disorders.

### Description of Related Art

**[0002]** Interactions between Notch receptors and their ligands represent an evolutionarily conserved pathway important not only for cell fate decisions but also in regulating lineage decisions in hematopoiesis and in the developing thymus (Artavanis-Tsakonas *et al.*, 1999, *Science* 284:770-776; Skokos *et al.*, 2007; *J Exp Med* 204:1525-1531; and Amsen *et al.*, 2004, *Cell* 117:515-526). It has been recently shown that Dll4-Notch1 inhibition leads to a complete block in T cell development accompanied by ectopic appearance of B cells and an expansion of dendritic cells (DC) that can arise from Pro-T cell to DC fate conversion within the thymus (Hozumi *et al.*, 2008, *J Exp Med* 205(11):2507-2513; Koch *et al.*, 2008, *J Exp Med* 205(11):2515-2523; and Feyerabend *et al.*, 2009, *Immunity* 30:1-13). Thus, there is accumulating evidence that Notch signaling is critical for the determination of cell fate decision from hematopoietic progenitor cells. Furthermore, a feedback control of regulatory T cell (Treg) homeostasis by DCs *in vivo* has been shown (Darrasse-Jèze *et al.*, 2009, *J Exp Med* 206(9):1853-1862). However, the role of Notch signaling in controlling the origin and the development of DCs and consequently Treg homeostasis is still unknown. This is a question clinically important because identifying new methods of inducing Treg expansion could be used as a treatment for autoimmunity diseases and disorders.

**[0003]** The nucleic acid and amino acid sequences of human Dll4 (hDll4) are shown in SEQ ID NOS:1 and 2, respectively. Dll4 antagonists and their uses are disclosed in WO 2007/143689, WO 2007/070671, WO 2008/076379, WO 2008/042236, and WO/2008/019144.

## BRIEF SUMMARY OF THE INVENTION

**[0004]** The present invention is based in part on the observation by the present inventor that an antibody, which specifically binds Dll4 and blocks Dll4 binding to Notch receptors, is able to fully

prevent a progression of Experimental Autoimmune Encephalomyelitis (EAE) in mice, an animal model for human multiple sclerosis, while a control antibody does not prevent EAE. Furthermore, the present inventor has discovered that this effect of anti-Dll4 antibody is associated with the increased number of Treg cells. In addition, it has been further observed that an anti-Dll4 antibody prevents an increase in blood glucose level and preserves the number and morphology of pancreatic islets in NOD/ShiLtJ mice, an animal model for type 1 diabetes, and such effects are, at least in part, mediated by the expansion of Tregs.

**[0005]** Thus, in a first aspect, the invention features a method of increasing the number of Treg cells, comprising administering an effective amount of a Dll4 antagonist to a subject in need thereof, wherein the Dll4 antagonist blocks the interaction between Dll4 and a Notch receptor and the number of Treg cells is increased.

**[0006]** In a second aspect, the invention features a method of treating or ameliorating a disease, disorder, or condition in which increasing the number of Treg cells is beneficial, comprising administering a therapeutically effective amount of a Dll4 antagonist to a subject in need thereof. The disease or disorder treatable by the methods of the invention is any disease, disorder, or condition which is benefitted, *i.e.*, improved, ameliorated, inhibited or prevented by removal, inhibition or reduction of Dll4 activity, thereby increasing the number of Treg cells in the treated subject. Such diseases, disorders, or conditions include, but are not limited to, a variety of autoimmune diseases, such as multiple sclerosis, diabetes mellitus type 1 and type 2, rheumatoid arthritis, Crohn's disease, Goodpasture's syndrome, Graves' disease, Guillain-Barré syndrome (GBS), Hashimoto's disease, idiopathic thrombocytopenic purpura, irritable bowel syndrome, lupus erythematosus, mixed connective tissue disease, myasthenia gravis, narcolepsy, pemphigus vulgaris, pernicious anemia, polymyositis, primary biliary cirrhosis, Sjögren's syndrome, ulcerative colitis, vasculitis, Wegener's granulomatosis, and the like, as well as organ transplant rejections and GVHD.

**[0007]** In one embodiment, the Dll4 antagonist to be used in the methods of the invention is a Dll4 antibody or fragment thereof ("anti-Dll4 Ab" or "Dll4 Ab") that specifically binds Dll4 with high affinity and blocks the binding of Dll4 to the Notch receptors and/or blocks the Dll4-Notch signal pathways. The antibody may be polyclonal, monoclonal (mAb), chimeric, humanized, or a wholly human antibody or fragment thereof. The antibody fragment may be a single chain antibody, an Fab, or an $(Fab')_2$.

**[0008]** In one embodiment, the Dll4 Ab or antigen-binding fragment thereof binds an epitope within the N-terminal domain (residues S27-R172), or the Delta/Serrate/Lag-2 (DSL) domain (residues V173-C217), or the N-terminal-DSL domain (residues S27-C217), of hDll4 (SEQ ID NO:2). In another embodiment, the Dll4 Ab or antigen-binding fragment thereof binds an epitope within one of the EGF domains, *i.e.*, at about amino acid residues Q218-N251 (domain 1), E252-D282 (domain 2), D284-E322 (domain 3), E324-E360 (domain 4), S362-E400 (domain 5), K402-E438 (domain 6), H440-E476 (domain 7), or S480-E518 (domain 8), of hDll4 (SEQ ID

NO:2). In some embodiments, the antibody or antibody fragment may bind a conformational epitope involving more than one of the epitopes enumerated above. The Dll4 Ab or fragment thereof to be used in the methods of the invention is capable of binding human Dll4 with high affinity and has an equilibrium dissociation constant ($K_D$) of about 1 nM or less, about 500 pM or less, about 300 pM or less, about 200 pM or less, about 100 pM or less, or about 50 pM or less, as measured by surface plasmon resonance.

**[0009]** In one embodiment, the Dll4 Ab or fragment thereof comprises a heavy chain variable region (HCVR) comprising three heavy chain complementarity determining regions, HCDR1, HCDR2 and HCDR3, having the amino acid sequences of SEQ ID NOS: 22, 24 and 26, respectively. In another embodiment, the antibody or fragment thereof comprises a light chain variable region (LDVR) comprising three light chain complementarity determining regions, LCDR1, LCDR2 and LCDR3, having the amino acid sequences of SEQ ID NOS:30, 32 and 34, respectively. In another embodiment, the Dll4 Ab or fragment thereof comprises the heavy and light chain CDR sequences comprising a CDR sequence combination of SEQ ID NOS:22, 24, 26, 30, 32 and 34. In yet another embodiment, the Dll4 Ab comprises a HCVR comprising the amino acid sequence of SEQ ID NO:20 or 116, or a LCVR comprising the amino acid sequence of SEQ ID NO:28 or 118. In yet another embodiment, the Dll4 Ab comprises a HCVR/LCVR combination of SEQ ID NO:20/28 (REGN281) or 116/118 (REGN421).

**[0010]** In certain embodiments, the Dll4 Ab comprises a heavy chain CDR1/CDR2/CDR3 combination and a light chain CDR1/CDR2/CDR3 combination selected from: SEQ ID NO:6/8/10 and SEQ ID NO:14/16/18, respectively; SEQ ID NO:38/40/42 and SEQ ID NO:46/48/50, respectively; SEQ ID NO:54/56/58 and SEQ ID NO:62/64/66, respectively; SEQ ID NO:70/72/74 and SEQ ID NO:78/80/82, respectively; SEQ ID NO:86/88/90 and SEQ ID NO:94/96/98, respectively; and SEQ ID NO:102/104/106 and SEQ ID NO:110/112/114, respectively. In another embodiment, the Dll4 Ab comprises a HCVR comprising the amino acid sequence of SEQ ID NO:4, 36, 52, 68, 84, or 100, or a LCVR comprising the amino acid sequence of SEQ ID NO:12, 44, 60, 76, 92, or 108. In yet another embodiment, the Dll4 Ab comprises a HCVR/LCVR combination selected from: SEQ ID NO:4/12 (REGN279); SEQ ID NO:36/44 (REGN290); SEQ ID NO:52/60 (REGN306); SEQ ID NO:68/76 (REGN309); SEQ ID NO:84/92 (REGN310); and SEQ ID NO:100/108 (REGN289).

**[0011]** The nucleotide sequences encoding the amino acid sequences of SEQ ID NOS:4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84, 86, 88, 90, 92, 94, 96, 98, 100, 102, 104, 106, 108, 110, 112, 114, 116 and 118, are shown as SEQ ID NOS:3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, 47, 49, 51, 53, 55, 57, 59, 61, 63, 65, 67, 69, 71, 73, 75, 77, 79, 81, 83, 85, 87, 89, 91, 93, 95, 97, 99, 101, 103, 105, 107, 109, 111, 113, 115 and 117, respectively.

**[0012]** In another embodiment, the Dll4 antagonist usable in the methods of the invention is a fusion protein comprising at least one soluble Notch receptor or fragment thereof capable of binding Dll4, fused to a multimerizing component. In one embodiment, the soluble Notch receptor is human Notch1 or Notch4. In another embodiment, the Dll4 antagonist of the invention is a modified Dll4 protein that is capable of binding the Notch receptor(s) but such binding does not result in activation of the receptor(s). In certain embodiments, the Dll4 antagonist of the invention is a fusion protein comprising the extracellular domain of Dll4 or a fragment thereof fused to a multimerizing component, such as an immunoglobulin domain, for example, an Fc domain of a human IgG. In certain embodiments, the Dll4 antagonists include small molecules and other agents that can block Dll4-Notch interactions.

**[0013]** In a third aspect, the invention features a method of preventing or reducing an occurrence or recurrence of an autoimmune disease or disorder, as described above, in a subject who is predisposed or susceptible to developing the disease or disorder, comprising administering to the subject a prophylactically effective amount of a Dll4 antagonist. In a related embodiment, the invention further features a method of preventing or reducing a possibility of an organ transplant rejection or GVHD in a transplant recipient, comprising administering a prophylactically effective amount of a Dll4 antagonist to the recipient before and/or after the transplantation.

**[0014]** In a fourth aspect, the invention features a method of preventing, treating or ameliorating an autoimmune disease or disorder, or an organ transplant rejection, comprising administering to a subject in need thereof an effective amount of a Dll4 antagonist in combination with an additional therapeutic agent, for example, an immunosuppressive agent or immunosuppressant, anti-inflammatory agent, analgesic agent, blood glucose lowering agent (*e.g.*, insulin, insulin analogues, and the like), many of which may have overlapping therapeutic effects of one another. Suitable immunosuppressants to be used in combination with the Dll4 antagonist include, but are not limited to, glucocorticoids, cyclosporin, methotrexate, interferon β (IFN-β), tacrolimus, sirolimus, azathioprine, mercaptopurine, opioids, mycophenolate, TNF-binding proteins, such as infliximab, eternacept, adalimumab, and the like, cytotoxic antibiotics, such as dactinomycin, anthracyclines, mitomycin C, bleomycin, mithramycin, and the like, antibodies targeting immune cells, such as anti-CD20 antibodies, anti-CD3 antibodies, and the like. Suitable anti-inflammatory agents and/or analgesics for combination therapies with anti-Dll4 antagonists include, corticosteroids, non-steroidal anti-inflammatory drugs (NSAIDs), such as aspirin, ibuprofen, naproxen and the like, TNF-α antagonists, IL-1 antagonists, IL-6 antagonists, acetaminophen, morphinomimetics, and the like.

**[0015]** In a fifth aspect, the invention features a pharmaceutical composition comprising a Dll4 antagonist, at least one additional therapeutic agent, and a pharmaceutically acceptable carrier. In one embodiment, the Dll4 antagonist is a Dll4 Ab or fragment thereof that specifically binds to Dll4 with high affinity and neutralizes Dll4 activities, and at least one additional therapeutic agent

is any of the immunosuppressants, anti-inflammatory agents, analgesics, glucose lowering agents, and the like, described above.

**[0016]** In a sixth aspect, the invention features a kit comprising a container comprising the pharmaceutical composition of the present invention, and a package insert with an instruction for use. In one embodiment, a kit may comprise a container comprising therein an antibody or fragment thereof that specifically binds hDll4, another container comprising therein at least one additional therapeutic agent described above.

**[0017]** Other objects and advantages will become apparent from a review of the ensuing detailed description.

## BRIEF DESCRIPTION OF THE FIGURES

**[0018] Fig. 1A-1B** show the effects of Dll4 blockade on the development of T cells and B cells. Mice were injected with anti-Dll4 antibody (REGN577) or control human Fc fragment (hFc). Fourteen days later, thymi were harvested and T-cell and B-cell subsets were evaluated by flow cytometry. **Fig. 1A:** Dot plots show the number of $CD4^-CD8^-$ (double negative thymic precursors or "DN"), $CD4^+CD8^+$ (double positive thymic precursors or "DP"), $CD4^+$ or $CD8^+$ (single positive thymic precursors or "SP"), and DN/$CD44^+CD25^-$ (thymic precursors at the DN1 stage) T cells. The numbers in the dot plots represent percentages (mean ± SEM) of T cell subpopulations among the total thymic cells. **Fig. 1B:** Histograms show the percentage (mean ± SD) of B cells ($B220^+$) among DN1 cells (*i.e.*, gated on $CD4^-CD8^-CD44^+CD25^-$).

**[0019] Fig. 2A-2B** show the effects of Dll4 blockade on B cell developmental stages in the bone marrow (**Fig. 2A**) and on B cell homeostasis in the spleen (**Fig. 2B**). The numbers in the dot plots represent percentages (mean ± SEM) of B cell subsets among the total cells in bone marrow or in spleen. GC: Germinal center B cells; T1 and T2: B cell subsets; M: Marginal B cells; and Fo: Follicular B cells.

**[0020] Fig. 3A-3D** show the effects of Dll4 blockade on dendritic cell (DC) development. **Fig. 3A:** Dot plots show the expansion of conventional DCs ("cDCs"; $B220^-CD11C^+$) and plasmacytoid DCs ("pDCs"; $PDCA1^+B220^+CD11C^+$) in the thymus upon anti-Dll4 Ab treatment. Numbers in dot plots represent average percentages (mean ± SEM) of DCs among total cells at day 14. **Fig. 3B:** The bar graphs show the kinetics of cDC and pDC expansion in the thymus of Dll4 Ab-treated mice (■) and hFc-control treated mice (□). **Fig. 3C:** Dot plots show the effects of Dll4 Ab on pre-DCs ($MHCII^{lo}CD11c^{int}CD135^+Sirp\text{-}\alpha^{int}$) and late pre-DCs ($MHCII^{lo}CD11c^{int}$) in the thymus. Numbers in dot plots represent average percentages (mean ± SEM) of pre-DCs among total cells at day 14. **Fig. 3D:** Dot plots show the presence of $MHCII^{lo}CD11c^{int}$ DCs in the DN1 ($CD4^-CD8^-CD44^+CD25^-$) pro-T cell population in the thymus of mice treated with Dll4 Ab, but not in the thymus of mice treated with hFc control Ab. Numbers in dot plots represent average number (mean ± SEM) of $MHCII^{lo}CD11c^{int}$ DCs among DN1 pro-T cell population at day 3.

**[0021] Fig. 4** shows the effect of Dll4 blockade on the development of intra-thymic alternative DC lineage into immature DCs (imDCs) originating from a common T/DC DN1 progenitor. DN1 $CD45.1^+Lin^-$ sorted cells were intra-thymically transferred into $CD45.2^+$ host mice treated with Dll4 Ab (■) or hFc control Ab (□).

**[0022] Fig. 5** shows the effect of Dll4 blockage on serum levels of CSF-1 (M-CSF), a key cytokine involved in DC development. Serum CSF-1 levels of mice untreated (▨), or treated with isotype control Ab (□), or Dll4 Ab (■) were measured by enzyme-linked immunosorbent assay (ELISA).

**[0023] Fig. 6** shows the effects of the genetic Dll4 deletion, upon tamoxifen treatment, on B cell and DC homeostasis in DLL4COIN mice containing a tamoxifen-inducible Cre recombinase construct, CreERT2. Numbers in dot plots represent average percentages (mean ± SEM) of B cells and both pDCs and cDCs among total cells in the thymus.

**[0024] Fig. 7A-7C** show the effects of Dll4 blockade/deletion on Treg homeostasis. **Fig. 7A:** Dot plots show an expansion of Tregs within the thymus of mice treated with Dll4-Ab for two weeks, compared to mice treated with hFc control Ab. Numbers in dot plots represent average percentages (mean ± SEM) of Tregs among $CD3^+CD4^+$ T cells in the thymus. **Fig. 7B:** Bar graphs show the kinetics of Treg development in thymus (upper panel) and spleen (lower panel), respectively, of the mice treated with Dll4 Ab (■) and hFc control Ab (□). **Fig. 7C:** Dot plots show an expansion of Tregs within the thymus of DLL4COIN mice treated with tamoxifen (TAM), compared to control DLL4COIN treated with corn oil control. Numbers in dot plots represent average percentages (mean ± SEM) of Tregs among $CD3^+CD4^+$ T cells in the thymus.

**[0025] Fig. 8A-8B** show the effects of Dll4 blockade on DC (**Fig. 8A**) and Treg homeostasis (**Fig. 8B)** in the thymus of mice expressing human Dll4 (hDll4) observed at days 7 and 14 after Dll4-Ab (REGN421) treatment (1 mg/kg or 5 mg/kg) or hFc treatment (5 mg/kg), twice per week for 2 weeks and at day 28 after the cessation of treatment. Numbers in dot plots represent average percentages (mean ± SEM) of pDCs and cDCs (**Fig. 8A**) or Tregs (**Fig. 8B**) among total cells in the thymus.

**[0026] Fig. 9A-9B** show the effects of Dll4 blockade in Experimental Autoimmune Encephalomyelitis (EAE) mouse model. **Fig. 9A:** The graph shows EAE disease incidence rates (%) per treatment group. **Fig. 9B:** The graph shows the development of EAE based on average disease scores. Treatment was with anti-Dll4 Ab (REGN577) pre-induction (▼); isotype control Ab pre-induction (♦); REGN577 post-induction (▲); or anti-VLA-4 Ab (PS/2) pre-induction (■).

**[0027] Fig. 10** shows the effects of Dll4 blockade on IL-17 and IFN-γ production in the lymph nodes of EAE mice. The levels of IL-17 (left panel) and IFN-γ (right panel) in the lymph nodes of EAE mice treated with Dll4 Ab (■) or hFc control Ab (□) were measured on days 12 and 18 by ELISA.

**[0028] Fig. 11A-11E** show the effects of Dll4 Ab in a NOD mouse diabetic model. **Fig. 11A** shows the % diabetes incidence (two consecutive readings of blood glucose level higher than 250 mg/dL) among the mice that received either hFC control Ab (●) or anti-Dll4 Ab (REGN577) (■) at 9 weeks of age. The % diabetes incidence of five mice that had been treated with the Dll4 Ab and subsequently injected with PC61 Ab at 20 weeks is also shown (♦). PC61 Ab is an anti-CD25 antibody and depletes Treg cells. **Fig. 11B** shows the measurement by ELISA of anti-insulin autoantibody (□) and anti-glutamic acid decarboxylase 65 (GAD65) autoantibody (■) productions in NOD mice treated with Dll4 Ab or hFc control, compared to untreated wild type (WT) mice. **Fig. 11C** shows pancreatic sections stained with Hematoxylin and Eosin (H&E) of NOD mice treated with Dll4 Ab (left panel) or hFc control (right panel). Black arrows indicate individual pancreatic islets and white arrow indicates infiltrating cells within the islet (right panel). **Fig. 11D** shows the number of pancreatic islets (left panel) or % of infiltrated pancreatic islets (right panel) in the pancreas of hFc control-treated (□) or Dll4 Ab-treated (■) mice. **Fig. 11E** shows the changes in blood glucose level in mice treated, at the onset of the disease, with Dll4 Ab (●) or hFc control (□), over 42 days after the treatment.

## DETAILED DESCRIPTION

**[0029]** Before the present methods are described, it is to be understood that this invention is not limited to particular methods, and experimental conditions described, as such methods and conditions may vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims.

**[0030]** As used in this specification and the appended claims, the singular forms “a”, “an”, and “the” include plural references unless the context clearly dictates otherwise. Thus for example, a reference to “a method” includes one or more methods, and/or steps of the type described herein and/or which will become apparent to those persons skilled in the art upon reading this disclosure.

**[0031]** Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, the preferred methods and materials are now described. All publications mentioned herein are incorporated herein by reference in their entirety.

### Definitions

**[0032]** The term “Dll4 antagonists”, as used herein, include antibodies to Dll4 and fragments thereof capable of blocking the binding of Dll4 to a Notch receptor (such as Notch1 and Notch4) and/or blocking Dll4-Notch signal pathways (see, for example, WO 2008/076379), fusion

proteins comprising the extracellular domain of Dll4 fused to a multimerizing component, or fragments thereof (see for example, US patent publication nos. 2006/0134121 and 2008/0107648), peptides and peptibodies (see, for example, US patent no. 7,138,370), and the like, which block the interaction between Dll4 and a Notch receptor. Thus, in certain embodiments, the term also encompasses antagonists, such as small molecules, antibodies or antigen-binding fragments thereof, and the like, that specifically bind Notch receptors (*e.g.*, anti-Notch1 antibodies, anti-Notch4 antibodies, etc.) and block Dll4-Notch signal pathways.

**[0033]** The term "antibody", as used herein, is intended to refer to immunoglobulin molecules comprised of four polypeptide chains, two heavy (H) chains and two light (L) chains inter-connected by disulfide bonds. Each heavy chain is comprised of a heavy chain variable region (abbreviated herein as HCVR or $V_H$) and a heavy chain constant region ($C_H$). The heavy chain constant region is comprised of three domains, $C_H1$, $C_H2$ and $C_H3$. Each light chain is comprised of a light chain variable region (abbreviated herein as LCVR or $V_L$) and a light chain constant region. The light chain constant region is comprised of one domain, $C_L$. The $V_H$ and $V_L$ regions can be further subdivided into regions of hypervariability, termed complementarity determining regions (CDR), interspersed with regions that are more conserved, termed framework regions (FR). Each $V_H$ and $V_L$ is composed of three CDRs and four FRs, arranged from amino-terminus to carboxy-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, and FR4.

**[0034]** Methods and techniques for identifying CDRs within HCVR and LCVR amino acid sequences are known in the art and can be applied to identify CDRs within the specified HCVR and/or LCVR amino acid sequences disclosed herein. Conventions that can be used to identify the boundaries of CDRs include 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

**[0035]** Substitution of one or more CDR residues or omission of one or more CDRs is also possible. Antibodies have been described in the scientific literature in which one or two CDRs can be dispensed with for binding. Padlan *et al.* (1995 FASEB J. 9:133-139) analyzed the contact regions between antibodies and their antigens, based on published crystal structures, and concluded that only about one fifth to one third of CDR residues actually contact the antigen. Padlan also found many antibodies in which one or two CDRs had no amino acids in contact with an antigen (see also, Vajdos *et al.* 2002 J Mol Biol 320:415-428).

**[0036]** CDR residues not contacting antigen can be identified based on previous studies (for example, residues H60-H65 in CDRH2 are often not required), from regions of Kabat CDRs lying outside Chothia CDRs, by molecular modeling and/or empirically. If a CDR or residue(s) thereof is omitted, it is usually substituted with an amino acid occupying the corresponding position in another human antibody sequence or a consensus of such sequences. Positions for substitution within CDRs and amino acids to substitute can also be selected empirically. Empirical substitutions can be conservative or non-conservative substitutions.

**[0037]** The term "antibody" also encompasses antibodies having a modified glycosylation pattern. In some applications, modification to remove undesirable glycosylation sites may be useful, or *e.g.*, removal of a fucose moiety to increase antibody dependent cellular cytotoxicity (ADCC) function (see Shield *et al.* (2002) JBC 277:26733). In other applications, removal of N-glycosylation site may reduce undesirable immune reactions against the therapeutic antibodies, or increase affinities of the antibodies. In yet other applications, modification of galactosylation can be made in order to modify complement dependent cytotoxicity (CDC).

**[0038]** The term "antigen-binding fragment" of an antibody (or simply "antibody fragment"), as used herein, refers to one or more fragments of an antibody that retain the ability to specifically bind to hDll4, or any other intended target proteins. An antibody fragment may include a Fab fragment, a $F(ab')_2$ fragment, a Fd fragment, a Fv fragment, a single-chain Fv (scFv) molecule, a dAb fragment, minimal recognition units consisting of the amino acid residues that mimic the hypervariable region of an antibody (*e.g.*, a fragment containing a CDR, or an isolated CDR). Other engineered molecules, such as diabodies, triabodies, tetrabodies and minibodies, are also encompassed within the expression "antigen-binding fragment", as used herein. In certain embodiments, antibody or antibody fragments of the invention may be conjugated to a therapeutic moiety ("immunoconjugate"), such as a cytotoxin, a chemotherapeutic drug, an immunosuppressant or a radioisotope.

**[0039]** 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.

**[0040]** 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)).

**[0041]** 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 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.

**[0042]** The term "human antibody", as used herein, is intended to include antibodies having variable and constant regions derived from human germline immunoglobulin sequences. The human mAbs of the invention may include amino acid residues not encoded by human germline immunoglobulin sequences (*e.g.*, mutations introduced by random or site-specific mutagenesis *in vitro* or by somatic mutation *in vivo*), for example in the CDRs and in particular CDR3. However, the term "human antibody", as used herein, is not intended to include mAbs in which CDR sequences derived from the germline of another mammalian species (*e.g.*, mouse), have been grafted onto human FR sequences.

**[0043]** The fully-human anti-Dll4 antibodies disclosed herein may comprise one or more amino acid substitutions, insertions and/or deletions in the framework and/or CDR regions of the heavy and light chain variable domains as compared to the corresponding germline sequences. Such mutations can be readily ascertained by comparing the amino acid sequences disclosed herein to germline sequences available from, for example, public antibody sequence databases. The present invention includes antibodies, and antigen-binding fragments thereof, which are derived from any of the amino acid sequences disclosed herein, wherein one or more amino acids within one or more framework and/or CDR regions are mutated to the corresponding residue(s) of the germline sequence from which the antibody was derived, or to the corresponding residue(s) of another human germline sequence, or to a conservative amino acid substitution of the corresponding germline residues(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 back-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 residues 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.

**[0044]** The present invention also includes anti-Dll4 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-Dll4 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, 2 or 1, conservative amino acid substitution(s) relative to any of the HCVR, LCVR, and/or CDR amino acid sequences disclosed herein. In one embodiment, a HCVR comprises the amino acid sequence of SEQ ID NO:116 with 10 or fewer conservative amino acid substitutions therein. In another embodiment, a HCVR comprises the amino acid sequence of SEQ ID NO:116 with 8 or fewer conservative amino acid substitutions therein. In another embodiment, a HCVR comprises the amino acid sequence of SEQ ID NO:116 with 6 or fewer conservative amino acid substitutions therein. In another embodiment, a HCVR comprises the amino acid sequence of SEQ ID NO:116 with 4 or fewer conservative amino acid substitutions therein. In yet another embodiment, a HCVR comprises the amino acid sequence of SEQ ID NO:116 with 2 or 1 conservative amino acid substitution(s) therein. In one embodiment, a LCVR comprises the amino acid sequence of SEQ ID NO:118 with 10 or fewer conservative amino acid substitutions therein. In another embodiment, a LCVR comprises the amino acid sequence of SEQ ID NO:118 with 8 or fewer conservative amino acid substitutions therein. In another embodiment, a LCVR comprises the amino acid sequence of SEQ ID NO:118 with 6 or fewer

conservative amino acid substitutions therein. In another embodiment, a LCVR comprises the amino acid sequence of SEQ ID NO:118 with 4 or fewer conservative amino acid substitutions therein. In yet another embodiment, a LCVR comprises the amino acid sequence of SEQ ID NO:118 with 2 or 1 conservative amino acid substitution(s) therein.

**[0045]** A "neutralizing" or "blocking" antibody, is intended to refer to an antibody whose binding to Dll4 results in inhibition of the biological activity of Dll4. This inhibition of the biological activity of Dll4 can be assessed by measuring one or more indicators of Dll4 biological activity. These indicators of Dll4 biological activity can be assessed by one or more of several standard *in vitro* or *in vivo* assays known in the art. For instance, the ability of an antibody to neutralize Dll4 activity is assessed by inhibition of Dll4 binding to a Notch receptor. Likewise, the term is also applicable to antibodies against other targets, such as Notch1 and Notch4; such antibodies inhibit the biological activities of the targets, thereby inhibiting Dll4-Notch interactions or signal pathways.

**[0046]** The term "specifically binds," or the like, means that an antibody or antigen-binding fragment thereof forms a complex with an antigen that is relatively stable under physiologic conditions. Specific binding can be characterized by an equilibrium dissociation constant of at least about $1x\ 10^{-6}$ M or less (e.g., a smaller $K_D$ denotes a tighter binding). Methods for determining whether two molecules specifically bind are well known in the art and include, for example, equilibrium dialysis, surface plasmon resonance, and the like. An isolated antibody that specifically binds hDll4 may, however, exhibit cross-reactivity to other antigens such as Dll4 molecules from other species. Moreover, multi-specific antibodies (e.g., bispecifics) that bind to hDll4 and one or more additional antigens are nonetheless considered antibodies that "specifically bind" hDll4, as used herein.

**[0047]** The term "$K_D$ ", as used herein, is intended to refer to the equilibrium dissociation constant of a particular antibody-antigen interaction.

**[0048]** The term "high affinity" antibody refers to those antibodies that bind Dll4 with a $K_D$ of about 1 nM or less, about 500 pM or less, about 400 pM or less, about 300 pM or less, about 200 pM or less, or about 100 pM or less, or about 50 pM or less, as measured by surface plasmon resonance, e.g., BIACORE™ or solution-affinity ELISA.

**[0049]** The term "surface plasmon resonance", as used herein, refers to an optical phenomenon that allows for the analysis of real-time biospecific interactions by detection of alterations in protein concentrations within a biosensor matrix, for example using the BIACORE™ system (Pharmacia Biosensor AB, Uppsala, Sweden and Piscataway, N.J.).

**[0050]** The term "epitope" is a region of an antigen that is bound by an antibody. Epitopes may be defined as structural or functional. Functional epitopes are generally a subset of the structural epitopes and have those residues that directly contribute to the affinity of the interaction. Epitopes may also be conformational, that is, composed of non-linear amino acids. In certain embodiments, epitopes may include determinants that are chemically active surface

groupings of molecules such as amino acids, sugar side chains, phosphoryl groups, or sulfonyl groups, and, in certain embodiments, may have specific three-dimensional structural characteristics, and/or specific charge characteristics. An epitope typically includes at least 3, and more usually, at least 5 or 8-10 amino acids in a unique spatial conformation.

**[0051]** The term "treatment" or "treat", as used herein, is intended to mean both prophylactic (or preventative) and therapeutic procedures, unless otherwise indicated. Subjects in need of treatment include not only those who have developed a particular condition, disorder or disease, but also those who are predisposed or susceptible to developing such a condition, disorder or disease and are benefited by prophylactic procedures so that the occurrences or recurrences, or the progression, if it occurs, of such a condition, disorder or disease are reduced, compared with those in the absence of the treatment.

**[0052]** By the phrase "therapeutically effective amount", "prophylactically effective amount", or "effective amount" is meant an amount that produces the desired effect for which it is administered. The exact amount will depend on the purpose of the treatment, the age and the size of a subject treated, the route of administration, and the like, and will be ascertainable by one skilled in the art using known techniques (see, for example, Lloyd (1999) The Art, Science and Technology of Pharmaceutical Compounding).

**General Description**

**[0053]** The present invention is based in part on the findings that the blockade of Dll4 by a Dll4-specific antibody results in the increased number of Treg cells, which, in turn, prevents, reduces, or delays a progression of EAE or diabetes in mice. For a description of fully human Dll4 Ab, including recombinant human Dll4 Ab, see International Patent Publication No. WO 2008/076379.

**Therapeutic Administration and Formulations**

**[0054]** The present invention provides methods of preventing, treating or ameliorating a disease or disorder in which increasing the number of Treg cells is beneficial, comprising administering a therapeutically effective amount of a pharmaceutical composition comprising a Dll4 antagonist, such as a Dll4 Ab. The pharmaceutical composition comprising a Dll4 antagonist can further comprise one or more additional therapeutic agents, such as immunosuppressive agents, anti-inflammatory agents, analgesic agents, blood glucose lowering agents, and the like (*see* the following section). The therapeutic compositions in accordance with the invention can be administered with suitable carriers, excipients, and other agents that are incorporated into formulations to provide improved transfer, delivery, tolerance, and the like. A multitude of appropriate formulations can be found in the formulary known to all pharmaceutical chemists: Remington's Pharmaceutical Sciences, Mack Publishing Company, Easton, PA. These formulations include, for example, powders, pastes, ointments, jellies, waxes, oils, lipids, lipid

(cationic or anionic) containing vesicles (such as LIPOFECTIN™), DNA conjugates, anhydrous absorption pastes, oil-in-water and water-in-oil emulsions, emulsions carbowax (polyethylene glycols of various molecular weights), semi-solid gels, and semi-solid mixtures containing carbowax. See also Powell *et al.* "Compendium of excipients for parenteral formulations" PDA (1998) J Pharm Sci Technol 52:238-311.

**[0055]** For systemic administration, a therapeutically effective dose can be estimated initially from *in vitro* assays. For example, a dose can be formulated in animal models to achieve a circulating concentration range that includes the $IC_{50}$ as determined in cell culture. Such information can be used to more accurately determine useful doses in humans. Initial dosages can also be estimated from *in vivo* data, *e.g.*, animal models, using techniques that are well known in the art. One having ordinary skill in the art could readily optimize administration to humans based on animal data.

**[0056]** The dose may vary depending upon the age and the size (*e.g.*, body weight or body surface area) of a subject to be administered, target disease, conditions, route of administration, and the like. For systemic administration of Dll4 antagonists, in particular, for Dll4 antibodies, typical dosage ranges for intravenous administration are at a daily dose of about 0.01 to about 100 mg/kg of body weight, about 0.1 to about 50 mg/kg, or about 0.2 to about 10 mg/kg. For subcutaneous administration, the antibodies can be administered at about 1 mg to about 800 mg, about 10 mg to about 500 mg, about 20 mg to about 400 mg, about 30 mg to about 300 mg, or about 50 mg to about 200 mg, at the antibody concentration of, at least, about 25 mg/ml, about 50 mg/ml, about 75 mg/ml, about 100 mg/ml, about 125 mg/ml, about 150 mg/ml, about 175 mg/ml, about 200 mg/ml, or about 250 mg/ml, at least, 1 to 5 times per day, 1 to 5 times per week, or 1 to 5 times per month. Alternatively, the antibodies can be initially administered via intravenous injection, followed by sequential subcutaneous administration.

**[0057]** 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.

**[0058]** The pharmaceutical composition can be also delivered in a vesicle, in particular a liposome (see Langer (1990) Science 249:1527-1533; Treat *et al.* (1989) in Liposomes in the Therapy of Infectious Disease and Cancer, Lopez Berestein and Fidler (eds.), Liss, New York, pp. 353-365; Lopez-Berestein, ibid., pp. 317-327; see generally ibid.).

**[0059]** 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.), CRC Pres., Boca Raton, Florida (1974). 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, in Medical Applications of Controlled Release, supra, vol. 2, pp. 115-138, 1984).

**[0060]** 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. 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.

**[0061]** Numerous reusable pen and autoinjector delivery devices have applications in the subcutaneous delivery of a pharmaceutical composition of the present invention. Examples include, but certainly are not limited to AUTOPEN™ (Owen Mumford, Inc., Woodstock, UK), DISETRONIC™ pen (Disetronic Medical Systems, Burghdorf, Switzerland), HUMALOG MIX 75/25™ pen, HUMALOG™ pen, HUMALIN 70/30™ pen (Eli Lilly and Co., Indianapolis, IN), NOVOPEN™ I, II and III (Novo Nordisk, Copenhagen, Denmark), NOVOPEN JUNIOR™ (Novo

Nordisk, Copenhagen, Denmark), BD™ pen (Becton Dickinson, Franklin Lakes, NJ), OPTIPEN™, OPTIPEN PRO™, OPTIPEN STARLET™, and OPTICLIK™ (sanofi-aventis, Frankfurt, Germany), to name only a few. Examples of disposable pen delivery devices having applications in subcutaneous delivery of a pharmaceutical composition of the present invention include, but certainly are not limited to the SOLOSTAR™ pen (sanofi-aventis), the FLEXPEN™ (Novo Nordisk), and the KWIKPEN™ (Eli Lilly).

**[0062]** 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 Dll4 antagonist, such as a Dll4 antibody, contained is generally about 0.1 to about 800 mg per dosage form in a unit dose; especially in the form of injection, it is preferred that the antibody is contained in about 5 to about 100 mg and in about 10 to about 250 mg for the other dosage forms.

**[0063]** In a certain embodiment, it may be desirable to administer the pharmaceutical compositions of the invention locally to the area in need of treatment; this may be achieved, for example, and not by way of limitation, by local infusion during surgery, topical application, *e.g.*, by injection, by means of a catheter, or by means of an implant, the implant being of a porous, non-porous, or gelatinous material, including membranes, such as sialastic membranes, fibers, or commercial skin substitutes.

**Combination Therapies**

**[0064]** In the therapeutic methods of the invention, a Dll4 antagonist may be provided alone or in combination with one or more additional therapeutic agents, such as immunosuppressive agents or immunosuppressants, anti-inflammatory agents, analgesic agents, direct or indirect blood glucose lowering agents, and the like. Suitable immunosuppressants include, but are not limited to, glucocorticoids, cyclosporin, methotrexate, interferon β (IFN-β), tacrolimus, sirolimus, azathioprine, mercaptopurine, opioids, mycophenolate, TNF-binding proteins, such as infliximab, eternacept, adalimumab, and the like, cytotoxic antibiotics, such as dactinomycin, anthracyclines, mitomycin C, bleomycin, mithramycin, and the like, antibodies targeting immune cells, such as anti-CD20 antibodies, anti-CD3 antibodies, and the like. Suitable anti-inflammatory agents and/or analgesics for combination therapies with anti-Dll4 antagonists include, corticosteroids, non-steroidal anti-inflammatory drugs (NSAIDs), such as aspirin, ibuprofen, naproxen and the like, TNF-α antagonists (*e.g.*, Infliximab or REMICADE® by Centocor Inc.; golimumab by Centocor Inc.; etanercept or ENBREL® by Amgen/Wyeth; adalimumab or HUMIRA® by Abbott Laboratories, and the like), IL-1 antagonists (*e.g.*, IL-1-binding fusion proteins, for example, ARCALYST® by Regeneron Pharmaceuticals, Inc., *see* US Patent No. 6,927,044; KINERET® by Amgen, and the like), IL-6 antagonists (*e.g.*, anti-IL-6 receptor antibodies as disclosed in US Patent No. 7,582,298, and ACTEMRA® by Roche), acetaminophen, morphinomimetics, and the

like. Suitable glucose lowering agents include, but are not limited to, insulin and analogs thereof, biguanides, sulfonamides and urea derivatives thereof, alpha-glucosidase inhibitors, thiazolidinedione and derivatives thereof, dipeptidyl peptidase-4 inhibitors, guar gum, repaglinide, nateglinide, exenatide, pramlintide, benfluorex, liraglutide, mitiglinide, aldose reductase inhibitors, and the like.

**[0065]** The Dll4 antagonist, such as hDll4 Ab or fragment thereof, and the additional therapeutic agent(s) described above can be co-administered together or separately. Where separate dosage formulations are used, the antibody or fragment thereof of the invention and the additional agents can be administered concurrently, or separately at staggered times, *i.e.*, sequentially, in appropriate orders.

**Kits**

**[0066]** The invention further provides an article of manufacturing or kit, comprising a packaging material, container and a pharmaceutical agent contained within the container, wherein the pharmaceutical agent comprises at least one Dll4 antagonist, such as Dll4 antibody, and at least one additional therapeutic agent, and wherein the packaging material comprises a label or package insert showing indications and directions for use. In one embodiment, the Dll4 antagonist and the additional therapeutic agent may be contained in separate containers.

## EXAMPLES

**[0067]** 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, temperature is in degrees Centigrade, pressure is at or near atmospheric, and figure error bars = mean ± SEM.

**[0068]** In the examples below, the following antibodies in Dulbecco's PBS (GIBCO® INVITROGEN™) 1X supplemented with 3% FCS, were used to stain cells for flow cytometry purpose: For DCs, antibodies against signal-regulatory protein α (Sirp-α; cat# P84; BD Biosciences), B220 (cat# RA3-6B2), PDCA-1 (cat# eBio927), CD8 (cat# 53-6.7), CD11b (cat# M1/70), MHCII (cat# M5/114.15.2), CD11c (cat# N418), and CD135 (cat# A2F10), respectively; for T, B and NK cells, antibodies against CD4 (cat# GK1.5 or L3T4), CD3 (cat# 145-2C11), CD25 (cat# PC61 or 7D4), CD44 (cat# IM7), FoxP3 (cat# FJK16s); and F4/80 (cat# BM8), NK1.1 (cat# PK136), IgM (cat# II/41), IgD (cat# 26-11c), CD43 (cat# S7), CD21 (cat# eBio4E3), HSA (cat# M1/69), and CD23 (cat# B3B4), respectively, (all from eBioscience).

**Example 1: Effect of Dll4 Blockade on Development of B cells, Dendritic Cells and T Cells**

**[0069]** It has been shown that Dll4-Notch1 inhibition leads to a complete block in T cell development accompanied by ectopic appearance of B cells and an expansion of dendritic cells (DC) that can arise from Pro-T cell to DC fate conversion within the thymus (Hozumi *et al.*, 2008, *J Exp Med* 205(11):2507-2513; Koch *et al.*, 2008, *J Exp Med* 205(11):2515-2523; and Feyerabend *et al.*, 2009, *Immunity* 30:1-13). It is, however, still unknown as to which specific stage of DC development is directly affected by the Dll4 blockade.

**[0070]** To answer this question, 6 week-old C57B1/6 mice (Jackson Labs) were injected subcutaneously with 5 or 25 mg/kg of anti-Dll4 Ab (REGN577) (n=5) or human Fc fragment (control) (n=5), twice a week for two weeks. REGN577 was prepared in-house based on the published sequence (WO 2007/143689). REGN 577 binds to human and mouse Dll4, but does not detectably binds human Dll1 and JAG1. Fourteen (14) days after the injection, thymi and spleens were harvested and digested at 37°C for 30 min in complete RPMI 1640 medium (Invitrogen) supplemented with 10% fetal calf serum (FCS) and containing Collagenase D (Sigma Aldrich). To stop the reaction, 2 mM EDTA was added and the organ suspension was passed through a 70-mm cell strainer. Bone marrow (BM) was collected from each mouse by flushing femurs and tibias in complete RPMI 1640 medium supplemented with 10% FCS and cells were resuspended in RPMI medium. T cell, B cell and DC subsets were evaluated by flow cytometry after the cells were stained with the antibodies against specific markers described above. The stained cells were run on a BD™ LSR II Flow Cytometer (BD Biosciences) and the data were analyzed using FlowJo software (version 8.8.6; Tree Star Inc.).

**[0071]** Fig. 1A and 1B show the T and B cell populations in the thymus. As shown in Fig. 1A, Dll4 blockade induced a significant increase in the number of double negative ("DN"; $CD4^-CD8^-$) T cells and a decrease in the number of double positive ("DP"; $CD4^+CD8^+$) T cells within the thymus. In addition, the same treatment induced an ectopic appearance of B cells within the thymus, which arose from Pro-T cells (*i.e.*, $CD44^+CD25^-CD4^-CD8^-$ cells at DN1 stage) (*see* Fig. 1B). In contrast, Dll4 blockade had no effect on B cell development in the bone marrow (Fig. 2A) or in the peripheral splenic B cell subpopulations (Fig. 2B). Furthermore, Dll4 blockade induced expansion of conventional DCs ("cDCs"; $B220^-CD11c^+$) and plasmacytoid DCs ("pDCs"; $PDCA1^+B220^+CD11C^+$) in the thymus (Fig. 3A), with significant expansion starting at day 7 ($p<0.001$) through day 14 ($p<0.001$) and continued through day 21 ($p<0.01$) (Fig. 3B) after the initial injection of Dll4 Ab. Numbers in dot plots of Fig. 3A represent average percentages of DCs among total cells at day 14. Further, DCs were expanded in the periphery of mice treated with Dll4 Ab (REGN577). Fold increases in percentage and absolute number of DCs in spleen upon treatment with Dll4 Ab, compared to the control mice (hFc-treated), are shown in Table 1.

**Table 1**

| Days after initial injection | Fold-increase in percentage | Fold-increase in absolute number |
|---|---|---|
| 3 | 1.0 | 1.0 |
| 7 | 1.1 | 1.1 |
| 14 | 1.6 | 2.0 |
| 21 | 1.3 | 1.7 |

**[0072]** It is known that lymphoid tissue cDCs, pDCs and monocytes share a common progenitor called "macrophage and DC precursor" or "MDP", which can be identified by its surface phenotype "$Lin^{-}cKit^{hi}CD115^{+}FLT3^{+}$", while a distinct progenitor called "common DC precursor" or "CDP" with "$Lin^{-}cKit^{lo}CD115^{+}FLT3^{+}$" is restricted to producing cDCs and pDCs. Although monocytes can develop many of the phenotypic features of DCs under inflammatory conditions, the cDC, pDC and monocytes lineages separate by the time they reach tissues, and neither monocytes nor pDCs develop into cDCs under steady state conditions. Unlike monocytes and pDCs, cDCs in lymphoid tissue are thought to emerge from the bone marrow as immature cells that must further differentiate and divide in lymphoid organs. Pre-DCs ($MHCII^{lo}CD11c^{int}CD135^{+}Sirp\text{-}\alpha^{int}$) and late pre-DCs ($MHCII^{lo}CD11c^{int}$), are precursors primarily to cDCs that arise in bone marrow (Liu *et al.*, 2009, *Science* 324:392-397).

**[0073]** To identify any effect of Dll4 Ab on DC progenitor homeostasis, the levels of MDP and CDP in the thymus, the bone marrow and the spleen were evaluated by flow cytometry. MDP and CDP were only detected in the bone marrow, but neither in the thymus nor in the spleen (data not shown). Furthermore, Dll4 blockade did not induce expansion of early progenitors in bone marrow compared to the control-treated mice. Thus, the result suggested that the Dll4 Ab could act at a later stage, *i.e.*, pre-DC stage, of DC development than MDP and CDP.

**[0074]** Accordingly, pre-DCs and late pre-DCs in the thymus and the bone marrow were searched for using the flow cytometry. As shown in Fig. 3C, $MHCII^{lo}CD11c^{int}$ DCs, which are normally present in the bone marrow, were only expanded in the thymus 14 days after the Dll4 Ab treatment ($p<0.001$), while no expansion of $MHCII^{lo}CD11c^{int}$ DCs was detected in the BM of the same mice (data not shown). Thus, the DC expansion originated from the pre-DC stage was restricted to thymus. To evaluate the origin of $MHCII^{lo}CD11c^{int}$ DCs in the thymus, flow cytometry was conducted to identify $MHCII^{lo}CD11c^{int}$ DCs in the DN1 ($CD4^{-}CD8^{-}CD44^{+}CD25^{-}$) pro-T cell population. As shown in Fig. 3D, $MHCII^{lo}CD11c^{int}$ DCs were detected within the DN1 pro-T cell population upon Dll4 blockade at day 3. No $MHCII^{lo}CD11c^{int}$ DCs were detected in the absence of Dll4 Ab treatment as well as within DN2, DN3 and DN4 T cell populations upon Dll4 Ab treatment (data not shown). No change in peripheral DC homeostasis was observed upon Dll4 Ab treatment (data not shown). Thus, Dll4 blockade induced a significant expansion of $MHCII^{lo}CD11c^{int}$ DCs within DN1 pro-T cell population in the thymus at day 3 ($p<0.01$) (Fig. 3D) with a peak of expansion at day 14 ($p<0.001$) (data not shown). Meanwhile, mature DC subsets

expanded at day 7 ($p$<0.001) through day 21 ($p$<0.01) in the thymus, as discussed above (*see* Fig. 3B).

**[0075]** To examine whether DC expansion could originate from uncommitted T-cell precursors, DN1 CD45.1$^{+}$Lin$^{-}$ sorted cells were intra-thymically transferred into CD45.2$^{+}$ host mice treated with anti-Dll4 Ab. It was found that CD45.1$^{+}$ cells were accumulated in DN1 stage (data not shown) and immature DCs (imDCs) were detected and expanded in thymus (Fig. 4) ($p$<0.01). No cells were detected in the control Ab-treated mice, possibly because most of DN1-transferred cells were eliminated by T cell negative selection. It was concluded that Dll4 blockade promotes the development of intra-thymic alternative DC lineage originating from a common T/DC DN1 progenitor.

**[0076]** Fms-like tyrosine kinase 3 ligand (Flt3-L) is sufficient and essential for the differentiation of bone marrow progenitors into DCs and the development of peripheral DCs. Serum levels of Flt3-L were unchanged in anti-Dll4 Ab-treated WT animals (data not shown). Furthermore, as shown in Tables 2 and 3 below, the percentages of DC in thymus were expanded in wild-type mice (WT) (Tables 2 and 3), FLt3-L knock-out mice (Flt3-L$^{-/-}$) ($p$<0.05) (Table 2), and Flt3-R knock-out mice (Flt3-R$^{-/-}$) ($p$<0.001) (Table 3), all treated with Dll4 Ab, compared to those treated with control Ab. Thus, Dll4 blockade induces a Flt3-independent DC expansion in thymus.

**Table 2**

| Mice | % DC in Thymus in Mice Treated with: | |
|---|---|---|
| | Control Ab | Dll4 Ab |
| WT | 0.04 ± 0.005 | 0.58 ± 0.13 |
| Flt3-L$^{-/-}$ | 0.04 ± 0.006 | 0.45 ± 0.13 |

**Table 3**

| Mice | % DC in Thymus of Mice Treated with: | |
|---|---|---|
| | Control Ab | Dll4 Ab |
| WT | 0.03 ± 0.003 | 0.37 ± 0.03 |
| Flt3-R$^{-/-}$ | 0.06 ± 0.01 | 0.44 ± 0.02 |

**[0077]** The ability of early T cell progenitors to re-derive towards a non-T cell phenotype has been observed (James P. Di Santo, 2010, *Science* 329:44-45). Gene array analysis was performed in thymocytes and pro-T cells to determine the effect of anti-Dll4 Ab treatment in genes implicated in T versus B and DC cell-lineage specification. It was found that the genes essential for T cell commitment (*e.g., Tcf7, Gata3, and Ets1*) were downregulated, while genes

(*Lyl1*, *Sfpi1)* that can each block T cell development, were up-regulated (data not shown; *see* Di Santo, 2010, *supra*). Most interestingly, genes controlling DC (*PU.1* and *Spi-B*) and B cell development were also up-regulated (data not shown; *see* M. Merad *et al.*, 2009, *Bood* 113:3418-3427). In addition, expression of *RelB* and *Id2* as well as interferon regulatory factors (*IRFs*) *2*, *4* and *8* -key transcription factors involved in DC subset development were increased (data not shown; *see* Merad *et al.*, 2009, *supra*). Finally, gene expression of CSF-1 (M-CSF), a key cytokine involved in DCs development, was found to be up-regulated upon anti-Dll4 Ab treatment ($p<0.05$; data not shown). Furthermore, CSF-1 serum levels were increased upon anti-Dll4 Ab treatment (Fig. 5; $p<0.05$) (*see* B. Francke, *et al.*, 2008, *Blood* 111:150-159). Thus, it can be concluded that Dll4-Notch signaling blockade down-regulates transcription factors specific for T cell lineage commitment, while up-regulating others crucial in DC development.

**Example 2: Effect of Dll4 deletion on T Cell Development**

**[0078]** To evaluate if the effect of Dll4 on DC development observed in Example 1 above was intrinsic to Dll4, DLL4COIN mice, in which Dll4 is conditionally inactivated, were prepared. "Conditional-by-inversion (COIN)" alleles are conditional alleles that rely on an inversible element ("COIN element") to provide recombinase-mediated conditional mutations. DLL4COIN mice contain a tamoxifen-inducible Cre recombinase construct, CreERT2, which encodes a Cre recombinase fused to a mutant estrogen ligand-binding domain (ERT2). CreERT2 is essentially inactive in the absence of tamoxifen and is also not activated by endogenous estrogens. Tamoxifen treatment of the mice will activate CreERT2 and cause the inversion of the COIN element, which abrogates the transcription of all exons downstream of the COIN insertion point, thereby knocking out Dll4. For details of CreERT2 recombinase system, *see* Feil *et al.*, 1997, *Biochemical and Biophysical Research Communications* 237:752-757.

**[0079]** DLL4COIN mice (n=6) were injected intraperitoneally (i.p.) with tamoxifen (TAM) (cat# T-5648, Sigma) at 3 mg/150 µl corn oil per mouse three (3) times per week for 2 weeks. DLL4COIN control mice (n=6) were given corn oil without tamoxifen. Likewise, wild type C5B1/6 mice were treated with tamoxifen (n=6) or corn oil only (n=6). Mice were monitored for signs of distress (*e.g.*, fur appearance, low activity, etc.), infections, and excessive loss of body weight. Mice were weighed approximately three times per week. Any mouse that lost more than 20% body weight was removed from the experiment. After 2 weeks of the treatment, thymi were harvested and the thymic cells were analyzed by flow cytometry.

**[0080]** As shown in Fig. 6, in the absence of Dll4 (*i.e.*, in tamoxifen-treated mice), B cells and both pDCs and cDCs were expanded in the thymus, compared to the corn oil-treated mice, indicating that the effects of Dll4 on DC development and homeostasis observed in Example 1 were indeed intrinsic to Dll4. Thus, Dll4-Notch signaling seems to sustain T cell commitment by suppressing non-T cell lineage potential within the pro-T cell population.

**Example 3: Effect of Dll4 Blockade or Dll4 Deletion on Tregs Homeostasis**

**[0081]** It has been recently shown that Tregs are essential for maintaining normal number of DCs. Upon Treg depletion there is a compensatory Fms-like tyrosine kinase 3 (Flt3)-dependent increase of DCs (Liu *et al.*, 2009, *supra*). Furthermore, two independent groups showed a feedback control of regulatory T cell homeostasis by DCs *in vivo*; *i.e.*, increasing the numbers of DCs leads to an increased Treg division and accumulation, which could prevent autoimmune disease development (Darrasse-Jeze G. *et al.*, 2009, *J Exp. Med.* 206(9):1853-1862; and Swee LK *et al.*, 2009, *Blood* 113(25):6277-6287).

**[0082]** To determine if Dll4 blockade could affect Treg homeostasis, Treg numbers in thymi of the mice treated with the Dll4 Ab or human Fc (control) in Example 1 were measured by flow cytometry. As shown in Fig. 7A, Dll4 blockade resulted in a robust expansion of Tregs within the thymus at day 14 after the initial injection. The expansion of Tregs started at day 7 ($p<0.001$) and reached a maximum effect at day 14 in the thymus ($p<0.001$) after the initial injection (*see* Fig. 7B), while in the periphery (*i.e.*, spleen) Tregs started appearing only between 14 and 21 days ($p<0.05$) (Fig. 7B and Table 4). In Table 4, fold increases in percentage and absolute number of Tregs in spleen upon treatment with Dll4 Ab, compared to the control mice (hFc-treated), are shown.

**Table 4**

| Days after initial injection | Fold-increase in percentage | Fold-increase in absolute number |
|---|---|---|
| 3 | 1.0 | 1.0 |
| 7 | 1.0 | 1.2 |
| 14 | 1.1 | 1.7 |
| 21 | 1.1 | 1.2 |

**[0083]** To evaluate if the observed Treg expansion was intrinsic to Dll4 molecule, Treg numbers in thymi of DLL4COIN mice from Example 2 were also measured by flow cytometry. As observed with the Dll4 blockade by Dll4 Ab, conditional inactivation of Dll4 by tamoxifen treatment also resulted in the expansion of Tregs in the thymus, compared to the corn-oil treated mice (*see* Fig. 7C) as well as wild-type mice treated with tamoxifen (data not shown). Thus, Dll4-Notch signaling sustains DCs and consequently Treg homeostasis and T cell commitment.

**[0084]** A similar experiment was conducted in mice expressing human Dll4 ("humanized Dll4 mice") using anti-Dll4 Ab (REGN421 having HCVR and LCVR sequences of SEQ ID NO:116 and 118, respectively), which is known to bind an N-terminal-DSL domain of human Dll4. The humanized Dll4 mouse was prepared by replacing the entire extracellular domain of the mouse Dll4 gene with the corresponding extracellular region of the human Dll4 gene (7 kb) in embryonic stem (ES) cells of F1 C57BL/6 /129. Homozygous hDll4 mice were generated and bred into C57BL/6 background. Humanized Dll4 mice were treated with 5 mg/kg of hFc (control; n=6), or 1 mg/kg (n=6) or 5 mg/kg (n=6) of REGN421 Ab twice per week for two weeks. Two

mice from each treatment group were sacrificed at day 7 and 2 more mice per group were sacrificed at day 14. The thymi were harvested and the cells were stained and examined by flow cytometry. The remaining mice were allowed to recover for additional 4 weeks without any treatment and, at day 28 after the cessation of treatment, they were sacrificed and the thymic cells were analyzed using flow cytometry. After two weeks of treatment, an increase of cDC and pDCs (Fig. 8A) as well as a significant increase in Treg population (Fig. 8B) was observed in the thymus of the anti-Dll4 Ab-treated mice ($p<0.01$). In the thymi of the mice that received Dll4 Ab for 2 weeks, followed by 4 weeks of non-treatment, both DC and Treg numbers returned to the normal level at the end of the period (Fig. 8A and 8B). Meanwhile, an expansion of DCs and Tregs was also observed in the periphery of Dll4-Ab treated mice, compared to hFc treated mice (data not shown).

**Example 4: Effect of Notch receptor blockade on Tregs**

**[0085]** It has been shown that an expansion of DCs is leading to an expansion of Tregs (Darrasse-Jeze G. *et al.*, 2009 ). As discussed above, it was observed that upon Dll4 blockade both DCs and Tregs were expanded in the thymus (Fig 3A and Fig 7A). In addition, an expansion of both percentages and absolute numbers of DCs and Tregs was also found in the periphery of Dll4-Ab treated mice (Tables 1 and 4). In order to determine if blockade of Notch receptors would lead to the same phenotype as Dll4 deletion, Nicastrin knockout (KO) mice ($Nic^{-/-}$) were studied. Nicastrin is a molecule involved in the Notch signaling pathway and genetic ablation of nicastrin in nicastrin deficient mice results in a blockade of signal transduction downstream of Notch receptors 1, 2, 3 and 4 (Aifantis *et al.*, un-published data). Nicastrin KO mice were shown to exhibit similar phenotype as the Dll4-deleted/blocked mice with an increased number of Tregs, both in percentage and in absolute number, in thymus as well as in spleen (*see* Table 5).

**Table 5**

| Treg | Thymus | | Spleen | |
|---|---|---|---|---|
| | **Control mice** | **Nicastrin KO mice** | **Control mice** | **Nicastrin KO mice** |
| Treg (%) in $CD3^+CD4^+$ cells | 3.3 ± 0.2 | 15.2 ± 2.0 ($p<0.1$) | 16.0 ± 1.3 | 33.9 ± 2.1 ($p<0.0001$) |
| Ratio of absolute numbers (Treg/Teff) | 0.04 ± 0.002 | 0.2 ± 0.03 ($p<0.01$) | 0.2 ± 0.01 | 0.6 ± 0.06 ($p<0.0001$) |

**[0086]** Finally, when bone marrow cells (BM) from $Nic^{-/-}$ mice were transferred into lethally irradiated WT mice, the expansion of thymic Tregs was observed in $Nic^{-/-}$→WT chimeras, suggesting that such an expansion was a cell-autonomous effect; and Dll4 blockade of the recipient mice with anti-Dll4 Ab had no additive effect (*see* Table 6).

**Table 6**

| BM Donors | % Treg in $CD3^+CD4^+$ Cells in Recipient WT Mice Treated with: | |
|---|---|---|
| | Control Ab | Anti-Dll4 Ab |
| WT | 3.6 ± 0.4 | 35 ± 4 |
| $Nic^{-/-}$ | 37 ± 2 | 41 ± 2 |

**[0087]** These results suggest that interruption of Dll4-Notch signaling by blocking either Dll4 or Notch receptors leads to similar phenotypes with regard to the expansion of Tregs.

**[0088]** To determine if the expansion of Tregs upon Dll4 blockade correlates with DC numbers (Darrasse-Jeze G. *et al.*, 2009, *supra*), mice lacking DCs were prepared and tested with the Dll4 Ab as in Example 1. Transgenic mice expressing primate diphtheria toxin receptor (DTR) are conferred with diphtheria toxin (DT) sensitivity to their cells, which are DT-insensitive otherwise. DT enters the cells via interaction of its B subunit with the cellular DTR and, upon endocytosis, the DT A subunit is released and catalyzes ADP-ribosylation of elongation factor 2, resulting in the inhibition of protein synthesis followed by rapid apoptosis in both mitotic and terminally differentiated cells. Specificity and timing of cell ablation can be determined by cell type-restricted promoter/enhancer elements and by the regimen of the toxin administration, respectively. To target DT sensitivity to DC, Jung *et al.* (2002, *Immunity* 17:211-220) have generated mice (CD11cre-DTR mice) that carry a transgene encoding a simian DTR-GFP (green fluorescent protein) fusion protein under the control of the murine CD11c promoter. Since CD11c encodes for all DCs, all murine DC subsets expressing CD11c are deleted upon administration of DT.

**[0089]** Thus-prepared transgenic mice lacking DCs were treated with the Dll4 Ab or hFc control according to the protocol described in Example 1. Fourteen (14) days after the treatment, thymi and spleens were harvested and prepared for analysis. The expression level of Dll4 on the surfaces of specific DC or T cell subsets was evaluated by flow cytometry in order to determine which specific subset the Dll4 Ab bound to. The results showed that DCs and T cells did not express detectable levels of Dll4 on their surface (data not shown). This observation is corroborated by the report that Dll4 is expressed on the surface of thymic epithelial cells (TECs) (Koch *et al.* 2008, *supra*). Most importantly, however, it was found that the Dll4 Ab treatment of mice lacking DCs was not able to induce expansion of Treg, while wild-type mice (*i.e.*, DC non-deleted mice) treated with Dll4 Ab significantly increased the proportion of Tregs among $CD3^+CD4^+$ cells ($p<0.001$), suggesting that the expansion of Tregs upon Dll4 Ab treatment was at least in part mediated via DC expansion.

**Example 5: Effect of Dll4 Blockade in Experimental Autoimmune Encephalomyelitis (EAE)**

**[0090]** $CD4^+CD25^+FoxP3^+$ natural regulatory T cells (*i.e.*, Tregs) play an important role in maintaining self-tolerance and suppress auto-immune diseases, such as type 1 diabetes, autoimmune encephalomyelitis, GVHD and inflammatory bowel disease (IBD) (Darrasse-Jeze G. *et al.*, 2009, *supra*; Swee LK *et al.*, 2009, *supra*; and McGreachy *et al.*, 2005, 175(5):3025-3032).

**[0091]** To see if the increased number of Tregs resulted from Dll4 blockade would prevent autoimmune diseases, the impact of Dll4 blockade on an EAE was studied in a mouse model. The EAE mouse model was established by injecting in the footpad of C57B1/6 mice with myelin oligodendrocyte glycoprotein (MOG) peptide emulsified in complete Freund adjuvant (CFA) followed (24 hours later) by Pertussis toxin (PTX) injection to induce disease. The disease score was determined based on the following symptoms: (0) no symptoms; (1) limp tail; (2) limp tail with hind-leg weakness; (3) partial hind-leg paralysis; (4) complete hind-leg paralysis; (5) paralysis of all limbs; and (6) moribund. Twelve to twenty-four hours prior to the immunization, mice in a pre-induction group (n=10) also received a subcutaneous injection of 25 mg/kg of either anti-Dll4 Ab (REGN577) or isotype control Ab (human antibody specific for CD20, prepared in-house according to the disclosure in US 2008/0260641), or PS/2 (rat/mouse IgG2b against murine integrin-like cellular adhesion molecule VLA-4; ATCC #CRL-1911), while mice in a post-induction group (n=10) received the same on the day the symptoms appeared. PS/2 Ab is known to exacerbate disease relapses and increase the accumulation of $CD4^+$ T cells in the central nervous system in a mouse model for relapsing experimental autoimmune encephalomyelitis (R-EAE) (Theien BE *et al.*, 2001, *J Clin Invest* 107(8):995-1006). The injections of antibodies were conducted twice a week, for two weeks. At the conclusion of the experiment, spinal cords of the mice were carefully removed, crushed and then incubated in a RPMI 1640 medium containing Collagenase D (Sigma Aldrich). EDTA at 2 mM was added to stop the reaction and the mixture was passed through a 70-mm cell strainer and the cell content was analyzed by flow cytometry.

**[0092]** As shown in Fig. 9A and 9B, the mice treated with isotype control Ab developed symptoms (*i.e.*, having disease scores more than "0") starting around 10-14 days and peaking between 15 and 21 days, after the MOG injections. In contrast, mice treated with Dll4 Ab were fully prevented from disease progression compared to mice treated with control Ab. Table 7 shows fold-increases in percentage and in absolute number of Tregs in thymus and spleen of the mice treated with Dll4 Ab, compared to mice treated with control Ab.

**Table 7**

| Days after MOG injection | Treg in Thymus | | Treg in Spleen | |
|---|---|---|---|---|
| | Fold-increase in percentage | Fold-increase in absolute number | Fold-increase in percentage | Fold-increase in absolute number |
| **12** | 2.46 | 0.77 | 1.08 | 1.46 |
| **18** | 4.88 | 2.67 | 1.23 | 1.89 |
| **21** | 1.41 | 1.01 | 1.85 | 4.77 |

**[0093]** Tregs seemed to expand primarily within the thymus at around day 18 and a significant expansion was seen in periphery (*i.e.*, spleen) only after day 21.

**[0094]** Under this particular experimental condition, Dll4 Ab treatment at the post-induction stage did not show significant improvement in disease progression. Dosages and/or frequency of Dll4 Ab administrations can be further adjusted within the knowledge of one skilled in the art. Importantly, however, the mice that had received pre-induction Dll4 Ab exhibited a significant decrease in cell infiltration into the spine at day 18, compared to those that had received control Ab (*see* Table 8 below). Cell infiltration observed in the spinal cord of the mice treated with control Ab could be a major contributor to the disease process in those mice.

**[0095]** As shown in Table 8, there was a 8-fold decrease ($p<0.0001$) in macrophages ($F4/80^+$), a 2.7-fold decrease ($p<0.0001$) in NK cells, 1.7-fold decrease ($p<0.001$) in CD11b cells, and 2.5-fold decrease ($p<0.001$) in B cells in spinal cord of mice treated with Dll4 Ab, compared to the spinal cord of mice treated with control Ab at day 21.

**Table 8**

| Days after MOG injection | Absolute Number of Infiltrating Cells in Spine (x $10^6$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Macrophages | | NK cells | | B cells | | $CD11b^+$ myeloid cells | |
| | Control | Dll4 Ab | Control | Dll4 Ab | Control | Dll4 Ab | Control | Dll4 Ab |
| **12** | 0.4 ± 0.05 | 0.3 ± 0.01 | 0.2 ± 0.03 | 0.1 ± 0.004 | 0.3 ± 0.005 | 0.2 ± 0.006 | 0.9 ± 0.09 | 0.6 ± 0.02 |
| **18** | 1.7 ± 0.5 | 0.2 ± 0.02 | 0.2 ± 0.06 | 0.1 ± 0.005 | 1.8 ± 0.2 | 1.0 ± 0.08 | 4.7 ± 0.7 | 1.8 ± 0.1 |
| **21** | 1.6 ± 0.1 | 0.2 ± 0.01 | 0.8 ± 0.07 | 0.3 ± 0.03 | 1.5 ± 0.1 | 0.6 ± 0.02 | 4.8 ± 0.1 | 2.9 ± 0.2 |

**[0096]** Furthermore, production of IL-17 and IFN-γ in lymph nodes in the mice treated with Dll4 Ab was significantly diminished ($p<0.001$) (Fig. 10). Thus, Dll4 could be involved in the pathogenesis of EAE by mediating Th1 development and Dll4 Ab treatment can prevent disease induction by blocking the secretion of Th1 and Th17 cytokines.

**Example 6. Effect of Dll4 Blockade on Diabetes**

**[0097]** The effect of Dll4 blockade on diabetes was also tested in NOD/ShiLtJ mice ("NOD mice"), a polygenic model for type 1 diabetes (Makino S *et al.*, 1980, *Jikken Dobutsu* 29 (1):1-13; Serreze DV *et al.*, 1997, *J Immunol* 158 (8):3978-86). Diabetes in NOD/ShiLtJ mice is

characterized by insulitis and leukocytic infiltration of the pancreatic islets. Marked decreases in pancreatic insulin content occur spontaneously in females at about 12 weeks of age and several weeks later in males. Consequently, plasma glucose levels increase to greater than 250mg/dL. NOD mice were checked twice a week for blood glucose levels, using a ONETOUCH® mini (LifeScan, Inc.). The mice were considered diabetic after two consecutive readings over 250 mg/dL of blood glucose. The onset of diabetes was dated from the first of the sequential diabetic measurements. The mice were injected with hFc (n=5) or anti-Dll4 Ab (Regn577) (n=10) 25mg/kg twice per week for 7 weeks starting at 9 weeks of age. Blood glucose levels were monitored once a week with blood samples from the tail.

**[0098]** As shown in Fig. 11A, mice treated with hFc started developing spontaneous diabetes with blood glucose levels higher than 250 mg/dL after 13 weeks of age (●). In contrast, mice treated with anti-Dll4 Ab (REGN577) showed no sign of increased glucose level through 25 weeks of age (■) and the measurements are continuing for additional 10 weeks. Dll4-Ab treatment before the diabetes onset prevented the development of diabetes and the treated animals did not seem to ever develop diabetes. Interestingly, when 5 out of 10 mice treated with Dll4 Ab were injected with anti-CD25 (PC61) mAb at 20 weeks of age in order to deplete the Tregs (♦), their blood glucose levels started increasing 1-2 weeks later and the mice became diabetic. This indicated that the preventive effect of Dll4 Ab on type I diabetes was mediated, at least in part, by Tregs (Fig 11A).

**[0099]** Insulin and GAD65 are two standard auto-antibodies that are found in the sera of diabetic NOD mice as well as of diabetic individuals. Accordingly, the serum levels of auto-antibodies in the mice treated with hFc control or Dll4 Ab were measured by ELISA. As shown in Fig. 11B, Dll4-Ab treatment blocked the production of anti-Insulin (□) and anti-GAD65 (■) auto-antibodies at levels similar to those of untreated WT C57Bl/6 (i.e., non-NOD mice; negative control animals). In contrast, NOD (diabetic) mice that received hFc control had high levels of auto-antibodies in their sera. In addition, when the pancreas sections of 23-week old mice, which had been treated with Dll4 Ab and showing no diabetic symptoms, were stained with H&E (Hematoxylin and Eosin), normal numbers of pancreatic islets (the cells that produce insulin or glucagon and their destruction is directly correlated with diabetes incidence) with preserved morphology were observed (Fig. 11C, left panel, and Fig. 11D, left panel). Further, no cellular infiltration within the islets was observed with Dll4 Ab-treated mice (Fig. 11C, left panel, and Fig. 11D, right panel). In contrast, diabetic animals, which had been treated with hFc control, had significantly lower numbers of pancreatic islets (Fig. 11C, right panel, and Fig. 11D, left panel) in their pancreas than the Dll4 Ab-treated mice and the remaining very few islets contained high levels of cellular infiltration (Fig. 11C, right panel, and Fig. 11D, right panel). Thus, Dll4 Ab was able to prevent diabetes completely for a prolonged period and its effect seemed to be, at least in part, mediated by the expansion of Tregs; however, it is possible that an additional

mechanism(s) may be involved in the protective effect of Dll4 Ab on pancreatic islets and/or insulin.

**[0100]** Actual blood glucose levels of the diabetic mice treated with Dll4 Ab were determined and compared with those of the mice treated with hFc control. Diabetic mice were treated with 25 mg/kg of Dll4 Ab (n=3) or control hFc (n=4) at the onset of disease (day 0). Upon Dll4 Ab treatment, diabetic mice significantly decreased the glucose level from about 350 mg/dL to a normal level (about 120-130 mg/dL) (Fig. 11E). This effect lasted for an average of 4 to 5 weeks. In general, it was further observed that, when diabetic mice having less than 350 mg/dL of blood glucose was treated with Dll4 Ab, their glucose levels dropped to the normal level and this effect lasted longer than those having more than 350 mg/dL of blood glucose at the time of treatment. This indicates that there is a certain window of opportunity for a prolonged and effective treatment for controlling blood glucose levels with Dll4 Ab. Thus, without being bound by any specific mechanisms described herein, these observations suggest that Dll4 antibodies have a great therapeutic potential for type I diabetes.

**[0101]** The results from the experiments above have revealed an existence of a previously unknown regulatory loop that controls the numbers of Treg cells and DCs *in vivo*. This regulatory circuit is likely to be essential to the balance between immunity and tolerance, but most importantly makes, for the first time, the link between three important components of the immune system, *i.e.*, Dll4-DCs-Tregs. Thus, a therapy with Dll4 antagonists presents an effective methodology to control Treg numbers *in vivo* and consequently control the progression of autoimmune diseases and related conditions.

## CLAIMS

1. A delta-like ligand 4 (Dll4) antagonist for use in preventing, treating or ameliorating a disease or disorder, in which increasing the number of regulatory T (Treg) cells is beneficial, wherein the antagonist blocks an interaction between Dll4 and Notch receptor, thereby increasing the number of Treg cells and the disease or disorder is prevented, treated or ameliorated.

2. A method of preventing, treating or ameliorating a disease or disorder, in which increasing the number of regulatory T (Treg) cells is beneficial, the method comprising administering a therapeutically effective amount of a delta-like ligand 4 (Dll4) antagonist to a subject in need thereof, wherein the antagonist blocks an interaction between Dll4 and Notch receptor, thereby increasing the number of Treg cells and the disease or disorder is prevented, treated or ameliorated.

3. The Dll4 antagonist according to claim 1 or the method according to claim 2, wherein the disease or disorder is an autoimmune disease.

4. The Dll4 antagonist or the method according to any one of claims 1 to 3, wherein the disease or disorder is selected from multiple sclerosis, rheumatoid arthritis, Crohn's disease, Goodpasture's syndrome, Graves' disease, Guillain-Barré syndrome (GBS), Hashimoto's disease, idiopathic thrombocytopenic purpura, irritable bowel syndrome, lupus erythematosus, mixed connective tissue disease, myasthenia gravis, narcolepsy, pemphigus vulgaris, pernicious anemia, polymyositis, primary biliary cirrhosis, Sjögren's syndrome, ulcerative colitis, vasculitis, and Wegener's granulomatosis.

5. The Dll4 antagonist or the method according to any one of claims 1 to 4, wherein the disease or disorder is multiple sclerosis.

6. The Dll4 antagonist or the method according to any one of the preceding claims, wherein the Dll4 antagonist is an antibody or fragment thereof that specifically binds human Dll4 (hDll4) and blocks Dll4-Notch signal pathways, or a fusion protein comprising the extracellular domain of Dll4 or a fragment thereof that is fused to the Fc domain of a human IgG.

7. The Dll4 antagonist or the method according to any one of the preceding claims, wherein the Dll4 antagonist is an antibody or fragment thereof that specifically binds human Dll4 (hDll4) and blocks Dll4-Notch signal pathways and comprises a heavy chain variable region (HCVR) comprising heavy chain CDR1, CDR2 and CDR3 sequences of SEQ ID NO:22, 24 and 26, respectively, and a light chain variable region (LCVR) comprising light chain CDR1, CDR2 and CDR3 sequences of SEQ ID NO:30, 32 and 34, respectively.

8. The Dll4 antagonist or the method according to claim 7, wherein the antibody or fragment thereof comprises a HCVR sequence of SEQ ID NO:20 or SEQ ID NO:116.

9. The Dll4 antagonist or the method according to claim 7, wherein the antibody or fragment thereof comprises a LCVR sequence of SEQ ID NO:28 or SEQ ID NO:118.

10. The Dll4 antagonist or the method according to any one of claims 7 to 9, wherein the antibody or fragment thereof comprises a HCVR/LCVR combination of SEQ ID NO:20/28 or 116/118.

11. The Dll4 antagonist according to any one of claims 1 and 3 to 10 in combination with at least one additional therapeutic agent selected from blood glucose lowering agent, immunosuppressant, anti-inflammatory agent, and analgesic agent.

12. The Dll4 antagonist according to claim 11, wherein the additional therapeutic agent is at least one selected from insulin and analogues thereof, glucocorticoides, cyclosporin, methotrexate, non-steroidal anti-inflammatory drugs (NSAIDs), TNF-α antagonists, IL-1 antagonists, IL-6 antagonists, and opioids.

13. The method according to any one of claims 2 to 10, further comprising coadministering a therapeutically effective amount of at least one additional therapeutic agent selected from blood glucose lowering agent, immunosuppressant, anti-inflammatory agent, and analgesic agent.

14. The method according to claim 13, wherein the additional therapeutic agent is at least one selected from insulin or analogues thereof, glucocorticoides, cyclosporin, methotrexate, non-steroidal anti-inflammatory drugs (NSAIDs), TNF-α antagonists, IL-1 antagonists, IL-6 antagonists, and opioids.

15. The Dll4 antagonist or the method according to any one of claims 11 to 14, wherein the Dll4 antagonist and at least one additional therapeutic agent are for concurrent or sequential administration.

16. Use of a delta-like ligand 4 (Dll4) antagonist as defined in any one of claims 1, 6-12 and 15 in preventing, treating or ameliorating a disease or disorder as defined in any one of claims 1 and 3-5.

17. Use of a delta-like ligand 4 (Dll4) antagonist in the manufacture of a medicament for preventing, treating or ameliorating a disease or disorder, in which increasing the number of regulatory T (Treg) cells is beneficial, wherein the antagonist blocks an interaction between Dll4 and Notch receptor, thereby increasing the number of Treg cells and the disease or disorder is prevented, treated or ameliorated.

18. The use according to claim 17, wherein the disease or disorder is an autoimmune disease.

19. The use according to claim 17 or 18, wherein the disease or disorder is selected from multiple sclerosis, rheumatoid arthritis, Crohn's disease, Goodpasture's syndrome, Graves' disease, Guillain-Barré syndrome (GBS), Hashimoto's disease, idiopathic thrombocytopenic purpura, irritable bowel syndrome, lupus erythematosus, mixed connective tissue disease,

myasthenia gravis, narcolepsy, pemphigus vulgaris, pernicious anemia, polymyositis, primary biliary cirrhosis, Sjögren's syndrome, ulcerative colitis, vasculitis, and Wegener's granulomatosis.

20. The use according to any one of claims 17 to 19, wherein the disease or disorder is multiple sclerosis.

21. The use according to any one of claims 17 to 20, wherein the Dll4 antagonist is an antibody or fragment thereof that specifically binds human Dll4 (hDll4) and blocks Dll4-Notch signal pathways, or a fusion protein comprising the extracellular domain of Dll4 or a fragment thereof that is fused to the Fc domain of a human IgG.

22. The use according to any one of claims 17 to 21, wherein the Dll4 antagonist is an antibody or fragment thereof that specifically binds human Dll4 (hDll4) and blocks Dll4-Notch signal pathways and comprises a heavy chain variable region (HCVR) comprising heavy chain CDR1, CDR2 and CDR3 sequences of SEQ ID NO:22, 24 and 26, respectively, and a light chain variable region (LCVR) comprising light chain CDR1, CDR2 and CDR3 sequences of SEQ ID NO:30, 32 and 34, respectively.

23. The use according to claim 22, wherein the antibody or fragment thereof comprises a HCVR sequence of SEQ ID NO:20 or SEQ ID NO:116.

24. The use according to claim 22, wherein the antibody or fragment thereof comprises a LCVR sequence of SEQ ID NO:28 or SEQ ID NO:118.

25. The use according to any one of claims 22 to 24, wherein the antibody or fragment thereof comprises a HCVR/LCVR combination of SEQ ID NO:20/28 or 116/118.