ISOLATION AND IDENTIFICATION OF T CELLS

FIELD OF THE INVENTION

[0001] The present invention relates generally to the field of diagnosis and treatment of autoimmune disease, such as multiple sclerosis (MS). More particularly, it concerns the isolation of antigen-specific T cells. In addition, the present invention concerns the use of antigen-specific T cells for the treatment of autoimmune disease, such as MS.

BACKGROUND

[0002] Intercellular recognition complexes formed by T cell receptors (TCR) on cytotoxic T lymphocytes or T helper cells and MHC/peptide complexes on antigen presenting cells (APC) are a common recognition component in a diverse set of cell-cell encounters that activate T cells both during the development of the repertoire of T cells within an individual organism (positive selection; negative selection; peripheral survival) and during the control (T helper) and effector stages (T killer) of an adaptive immune response.

[0003] In the adaptive immune response, antigens are recognized by hypervariable molecules, such as antibodies or TCRs, which are expressed with sufficiently diverse structures to be able to recognize any antigen. Antibodies can bind to any part of the surface of an antigen. TCRs, however, are restricted to binding to short peptides bound to class I or class II molecules of the major histocompatibility complex (MHC) on the surface of APCs. TCR recognition of a peptide/MHC complex triggers activation (clonal expansion) of the T cell.

[0004] TCRs are heterodimers composed of two chains which can be αβ (alpha-beta) or γδ (gamma-delta). The structure of TCRs is very similar to that of immunoglobulins (Ig). Each chain has two extracellular domains, which are immunoglobulin folds. The amino-terminal domain is highly variable and called the variable (V) domain. The domain closest to the membrane is the constant (C) domain. These two domains are analogous to those of immunoglobulins, and resemble Fab fragments. The V domain of each chain has three complementarity determining regions (CDR). Proximal to the membrane, each TCR chain has a short connecting sequence with a cysteine residue that forms a disulfide bond between both chains.

[0005] Genes encoding αβ and γδ heterodimers are only expressed in the T-cell lineage. The four TCR loci (α, β, γ and δ) have a germ-line organization very similar to that of Ig. α and γ chains are produced by rearrangements of V and J segments whereas β and δ chains are produced by rearrangements of V, D, and J segments. The gene segments for TCR chains are located on different chromosomes, except the δ-chain gene segments that are between the V and J gene segments of the α chain. The location of δ-chain gene segments has a significance: a productive rearrangement of α-chain gene segments deletes C genes of the δ-chain, so that in a given cell the αβ heterodimer cannot be co-expressed with the γδ receptor.

[0006] In mice, there are about 100 Vα and 50 Jα genes segments and only one Cα segment. The δ-chain gene family has about 10 V, 2 D, and 2 J gene segments. The β-chain gene family has 20-30 V segments and two identical repeats containing 1 Dβ, 6 Jβ and 1 Cβ. Finally, the γ-chain gene family contains 7 V and 3 different J-C repeats. In humans the organization is similar to that of mice, but the number of segments varies.

[0007] The rearrangements of gene segments in α and β chains is similar to that of Igs. The α chain, like the light chain of Ig is encoded by V, J, and C gene segments. The β chain, like the heavy chain of Ig, is encoded by V, D, and J gene segments. Rearrangements of α chain gene segments result in VJ joining and rearrangements of β chain result in VDJ joining. After transcription of rearranged genes, RNA processing, and translation, the α and β chains are expressed linked by a disulfide bond in the membrane of T cells.

[0008] TCR gene segments are flanked by recognition signal sequences (RSS) containing a heptamer and a nonamer with an intervening sequence of either 12 nucleotides (one turn) or 23 nucleotides (two turn). As in Igs, enzymes encoded by recombination-activating genes (RAG-1 and RAG-2) are responsible for the recombination processes. RAG1/2 recognize the RSS and join V-J and V-D-J segments in the same manner as in Ig rearrangements. Briefly, these enzymes cut one DNA strand between the gene segment and the RSS and catalyze the formation of a hairpin in the coding sequence. The signal sequence is subsequently excised.

[0009] The combinatorial joining of V and J segments in α chains and V, D and J segments in β chains produces a large number of possible molecules, thereby creating

a diversity of TCRs. Diversity is also achieved in TCRs by alternative joining of gene segments. In contrast to Ig, β and δ gene segments can be joined in alternative ways. RSS flanking gene segments in β and δ gene segments can generate VJ and VDJ in the β chain, and VJ, VDJ, and VDDJ on the δ chain. As in the case of Ig, diversity is also produced by variability in the joining of gene segments.

[0010] Hypervariable loops of the TCR known as complementarity determining regions (CDRs) recognize the composite surface made from a MHC molecule and a bound peptide. The CDR2 loops of α and β contact only the MHC molecule on the surface of APC, while the CDR1 and CDR3 loops contact both the peptide and MHC molecule. Compared with Ig, TCRs have more limited diversity in the CDR1 and CDR2. However, diversity of the CDR3 loops in TCRs is higher than that of Ig, because TCRs can join more than one D segment leading to augmented junctional diversity.

[0011] The pathogenesis of a number of autoimmune diseases is believed to be caused by autoimmune T cell responses to self-antigens present in the organism. Not all autoreactive T cells are deleted in the thymus, in contradiction with the clonal selection paradigm. Those T cells with TCRs for a broad spectrum of self-antigens represent part of the normal T-cell repertoire and naturally circulate in the periphery. It is unclear why autoreactive T cells are allowed, during their evolution, to undergo differentiation in the thymus and are accommodated in the periphery. While their physiological role is not understood, these autoreactive T cells, when activated, present a potential risk in the induction of autoimmune pathologies. Autoreactive T cells can also be isolated from normal individuals without the consequences of autoimmune diseases. It has been established that antigen recognition of autoreactivity by itself is not sufficient to mediate the autodestructive process. One of the prerequisites for autoreactive T cells to be pathogenic is that they must be activated.

[0012] Autoreactive T cells are implicated in the pathogenesis of autoimmune diseases, such as multiple sclerosis (MS) and rheumatoid arthritis (RA). The pathogenesis of autoreactive T cells in MS is generally held to arise from T cell responses to myelin antigens, in particular myelin basic protein (MBP). MBP-reactive T cells are found to undergo *in vivo* activation, and occur at a higher precursor frequency in blood and cerebrospinal fluid in patients with MS as opposed to control

individuals. These MBP-reactive T cells produce T_H1 cytokines, e.g. IL-2, TNFα, and γ-interferon (IFNγ), which facilitate migration of inflammatory cells into the central nervous system and exacerbate myelin-destructive inflammatory responses in MS.

[0013] Myelin-reactive T cells have also been shown to be involved in the pathogenesis of experimental autoimmune encephalomyelitis (EAE) in animals, which resembles MS. EAE can be induced actively in susceptible animals by injecting myelin proteins emulsified in an adjuvant or passively by injecting myelin-reactive T-cell lines and clones derived from myelin-sensitized animals. When activated *in vitro*, very small numbers of myelin-reactive T cells are required to induce EAE, while 100-fold more resting T cells with the same reactivity are incapable of mediating EAE.

[0014] EAE has been shown to be prevented and also treated by vaccination with inactivated myelin-reactive T cells, a procedure called T-cell vaccination (Ben-Nun *et al., Nature,* 1981; 292: 60-61). T-cell vaccination induces regulatory immune responses comprised of anti-idiotypic T cells and anti-ergotypic T cells, which lead to the depletion of myelin-reactive T cells. By depleting myelin-reactive T cells, therapeutic effects are observed in EAE and other experimental autoimmune disease models (Lider *et al., Science*, 1988; 239:820-822; Lohse *et al., Science*, 1989; 244: 820-822).

[0015] Due to the success in autoimmune disease models, T cell vaccination has recently advanced to clinical trials in patients with MS. Based on the results in experimental models such as EAE, it is believed that depletion of autoreactive T cells may improve the clinical course of MS and other autoimmune diseases.

[0016] In a pilot clinical trial, vaccination with irradiated autologous MBP-reactive T cell clones elicited $CD8^+$ cytolytic T cell responses that specifically recognized and lysed circulating MBP-reactive T cells (Zhang *et al., Science*, 1993; 261: 1451-1454, Medaer *et al.. Lancet* 1995: 346:807-808). Three subcutaneous inoculations with irradiated MBP-reactive T cell clones resulted in the depletion of circulating MBP-reactive T cells in patients with MS.

[0017] In a preliminary clinical trial, circulating MBP-reactive T cells were depleted in relapsing remitting MS patients and secondary progressive MS patients (Zhang *et al., J Neurol.*, 2002; 249:212-8), by vaccinating the patients with three subcutaneous injections of irradiated autologous MBP-reactive T cells. T cell vaccination was beneficial to each group of patients as measured by rate of relapse, expanded

disability scale score and MRI lesion activity. However, there was a trend for an accelerated progression after about twelve months following the last injection. The significance of the apparent accelerated progression is unknown, but may be associated with a gradual decline of the immunity induced by T cell vaccination against MBP-reactive T cells. In approximately 10-12% of the immunized patients, MBP-reactive T cells reappeared at about the same time as the accelerated progression. In some cases, the reappearing MBP-reactive T cells originated from different clonal populations that were not detected before vaccination, suggesting that MBP-reactive T cells may undergo clonal shift or epitope spreading. Clonal shift of MBP-reactive T cells has been observed in previous studies (Zhang *et al.* 1995) and may be associated with the on-going disease process.

[0018] Although T cell vaccination has been demonstrated to be effective for depleting myelin-reactive T cells and potentially beneficial for MS patients, there are several problems with the treatment. T cell vaccine treatment for each patient must be individualized because the T cell receptors of myelin-reactive T cells are highly diverse and vary between different MS patients (Vandevyver *et al.*, *Eur. J. Immunol.*, 1995; 25:958-968, Wucherpfennig *et al.*, *J. Immunol.*, 1994; 152:5581-5592, Hong *et al.*, *J. Immunol.*, 1999; 163:3530-3538).

[0019] In addition to being individualized for each patient, up to 8 weeks is required to produce a given T cell vaccine using current procedures. Production of a T cell vaccine begins with isolating mononuclear cells from the cerebrospinal fluid (CSFMCs) or peripheral blood (PBMCs) of a patient. The isolated mononuclear cells are then cultured with myelin peptides for 7-10 days to activate myelin-reactive T cells. Cultures are then tested for specific proliferation to myelin peptides by measuring [^{3}H]-thymidine incorporation in the presence of myelin peptides over a period of 3 days. Cultures testing positive for specific proliferation to myelin peptides are then serially diluted to obtain clonal T cell lines or directly expanded. The cells are then cultured up to 6-8 weeks to expand the T cells. When the final T cell vaccine product is clonal, the T cells are homogenous with a single pattern of Vβ-Dβ-Jβ gene usage. Usually, three to six of the clonal cell lines are combined to produce a heterogeneous formulation with multiple patterns of Vβ-Dβ-Jβ gene usage. When the final T cell vaccine product is produced by direct expansion, the T cells are heterogeneous with more than one pattern of Vβ-Dβ-Jβ gene usage.

[0020] The individualized nature of T cell vaccination and the prolonged cell culture needed for production of each vaccine make treatment expensive and labor intensive under current methodologies. The extended time required for cell culture also creates a significant risk of contamination. Finally, the likelihood of clonal shift or epitope spreading of myelin-reactive T cells may require the subsequent production of a T cell vaccine for each patient with a different pattern of Vβ-Dβ-Jβ gene usage.

[0021] Therefore, there exists a need to develop improved methods of isolating T cells with specificity for antigens, such as MBP, that may be used to produce T cell vaccines for the treatment of patients with T cell-mediated diseases such as MS. There also exists a need to develop improved methods for producing T cell vaccines with a heterogeneous pattern of Vβ-Dβ-Jβ gene usage to account for clonal shift of autoreactive T cells.

SUMMARY OF THE INVENTION

[0022] The present invention is generally directed to methods of isolating antigen-specific T cells and more particularly T cells specific for self or autoantigens. The methods for isolating one or more T cells specific for an antigen of interest generally comprise incubating a sample comprising T cells obtained from a patient with said antigen or a derivative thereof; selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR; and one or more second markers selected from the group consisting of IL-2, IFNg, TNFα, IL5, IL-10 and IL-13.

[0023] The methods of the invention are particularly useful for isolating autoreactive T cells which play a role in the pathogenesis of autoimmune diseases.

[0024] The methods of the invention also permit the diagnosis of autoimmune disease as well as monitoring the progression of the disease and for monitoring the efficacy of treatments for the disease.

[0025] The methods of the invention also allow the preparation of autologous T cell vaccines for the treatment of T cell related autoimmune diseases.

[0026] The methods for vaccine preparation generally involve the isolation of antigen-specific T cells as described above optionally followed by subsequent culturing steps which allows the expansion of the population of isolated antigen-specific T cells.

[0027] The invention *inter alia* is also directed to T cell vaccines and pharmaceutical compositions comprising antigen-specific T cells isolated using the methods of the invention.

[0028] The methods of the invention are also useful for characterizing T cell receptors and their encoding nucleic acids.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Figure 1 demonstrates FACS identification of cells expressing CD69 and γIFN (top) and CD69 and TNFα (bottom) in a multiple sclerosis patient before stimulation (left), after stimulation with residues 83-99 of MBP (middle), and after stimulation with residues 83-99 of MBP (right).

[0030] Figure 2 demonstrates FACS identification of cells expressing CD69 and γIFN (top) and CD69 and TNFα (bottom) in a healthy control patient before stimulation

(left), after stimulation with residues 83-99 of MBP (middle), and after stimulation with residues 83-99 of MBP (right).

DETAILED DESCRIPTION

1. Definitions

[0031] To aid in the understanding of the present invention, several terms are defined below.

[0032] "Autoantigen" or "self-antigen" as used herein refers to an antigen or epitope which is native to the mammal which is immunogenic in said mammal disease is conserved in that species of mammal and which may be involved in the pathogenesis of autoimmune.

[0033] "CD," "cluster of differentiation" or "common determinant" as used herein refers to cell surface molecules recognized by antibodies. Expression of some CDs is specific for cells of a particular lineage or maturational pathway, and the expression of others varies according to the state of activation, position, or differentiation of the same cells.

[0034] "Derived from" or "a derivative thereof," in the context of nucleotide sequences means that the nucleotide sequence is not limited to the specific sequence described, but also includes variations in that sequence, which may include nucleotide additions, deletions, substitutions, or modifications to the extent that the variations to the described sequence retain the ability to hybridize under moderate or highly stringent conditions to the complement of the described sequence. In the context of peptide or polypeptide sequences, "derived from" or "a derivative thereof" means that the peptide or polypeptide is not limited to the specific sequence described, but also includes variations in that sequence, which may include amino acid additions, deletions, substitutions, or modifications to the extent that the variations in the listed sequence retain the ability to elicit an immune response to the described sequence.

[0035] "Immunogenic," when used to describe a peptide or polypeptide, means the peptide or polypeptide is able to induce an immune response, either T cell mediated, antibody, or both.

[0036] "Immune-related disease" means a disease in which the immune system is involved in the pathogenesis of the disease. A subset of immune-related diseases are autoimmune diseases. Autoimmune diseases include, but are not limited to, rheumatoid arthritis, myasthenia gravis, multiple sclerosis, psoriasis, systemic lupus

erythematosus, autoimmune thyroiditis (Hashimoto's thyroiditis), Graves' disease, inflammatory bowel disease, autoimmune uveoretinitis, polymyositis, and certain types of diabetes. In view of the present disclosure, one skilled in the art can readily perceive other autoimmune diseases treatable by the compositions and methods of the present invention.

[0037] "PCR" means the polymerase chain reaction, for example, as generally described in U.S. Pat. No. 4,683,202 (issued July 28, 1987 to Mullis), which is incorporated herein by reference. PCR is an amplification technique wherein selected oligonucleotides, or primers, may be hybridized to nucleic acid templates in the presence of a polymerization agent (such as a DNA or RNA polymerase) and nucleotide triphosphates, whereby extension products may be formed from the primers. These products may then be denatured and used as templates in a cycling reaction that amplifies the number and amount of existing nucleic acids which may facilitate their subsequent detection. A variety of PCR techniques are known in the art and may be used in connection with the disclosure herein.

[0038] A "Peptide" or "polypeptide" is a linked sequence of amino acids and may be natural, synthetic, or a modification or combination of natural and synthetic.

[0039] "Primer" means an oligonucleotide, whether natural, synthetic, or a modification thereof, capable of acting as a point of initiation of nucleotide synthesis sufficiently complementary to a specific nucleotide sequence on a template molecule.

[0040] "Probe" means an oligonucleotide, whether natural, synthetic, or a modification thereof, capable of specifically binding to a sufficiently complementary nucleotide sequence.

[0041] "T cell mediated disease" means a disease arising as a result of T cells recognizing self-antigens.

[0042] "Treatment" or "treating," when referring to protection of an animal from a disease, means preventing, suppressing, repressing, or completely eliminating the disease. Preventing the disease involves administering a composition of the present invention to an animal prior to onset of the disease. Suppressing the disease involves administering a composition of the present invention to an animal after induction of the disease but before its clinical appearance. Repressing the disease involves administering a composition of the present invention to an animal after clinical appearance of the disease.

2. Isolation of Antigen-Specific T Cells

a. Isolation of Monoclonal Antigen-Specific T Cells

[0043] T cells may be activated and expanded in cell culture by incubation with an antigen target and antigen presenting cells. Once activated, T cells undergo a complex cascade of cell signaling which leads to the transcription and expression of many gene products. The invention described herein takes advantage of gene products specific for activated T cells for the identification and isolation of T cells with desired antigen specificity.

[0044] In a first aspect, the present invention is directed to a method for isolating a T cell that is specific for an antigen of interest. A sample comprising T cells is incubated with a particular antigen, which causes the activation of a T cell specific for the antigen of interest. The sample may be incubated with the antigen for 1 to 7 days. The sample may also be incubated with the antigen for less than 1 day. The sample may also be incubated with the antigen for less than 16 hours. The sample may also be incubated with the antigen for less than 12 hours. The sample may also be incubated with the antigen for less than 8 hours. The sample may also be incubated with the antigen for less than 4 hours. The sample may also be incubated with the antigen for less than 2 hours.

[0045] A T cell specific for the antigen of interest may then be isolated by selecting for T cells that express gene products of T cells activated as described above. Subsets of activated T cells may be isolated by selecting for T cells with subset-specific gene products or cell surface markers (e.g., CD4 vs. CD8).

[0046] The antigen of interest includes myelin basic protein (MBP), proteolipid protein (PLP), myelin oligodendrocyte glycoprotein (MOG), or a fragment thereof. The antigen of interest may also be an immunodominant fragment including, but not limited to, residues 83-99 or residue 151-170 of MBP. The antigen of interest may also be a combination of two or more individual antigens of interest.

[0047] The antigen or a derivative thereof, used to activate the T cells may be any immunogen which is capable of eliciting an immune response to the antigen of interest. The activating antigen may be the antigen of interest, or a derivative thereof. The activating antigen may be MBP, PLP, MOG, or a fragment and/or derivative thereof. The activating antigen may also be an immunodominant fragment including, but not limited to, residues 83-99 or residue 151-170 of MBP, or a fragment and/or derivative thereof. The activating antigen may also be a combination of two or more

individual activating antigens. The activating antigen may be used one or more times to activate T cells specific for an antigen of interest.

[0048] The T cells may be present in any sample comprising mononuclear cells. The sample may be isolated from the peripheral blood or cerebral spinal fluid of an MS patient or from the synovial fluid of a RA patient. T cells from patients with other autoimmune diseases may be similarly isolated from peripheral blood and/or tissues involved with the disease. Mononuclear cells may be enriched in the sample by using centrifugation techniques known to those in the art including, but not limited to, Ficoll® gradients. T cells may also be enriched in the sample by using positive selection, negative selection, or a combination thereof for expression of gene products of T cells.

[0049] The gene product for identifying or negatively selecting for activated T cells may be a cell surface marker or cytokine, or a combination thereof. Cell surface markers for identifying activated T cells include, but are not limited to, CD69, CD4, CD8, CD25, HLA-DR, CD28, and CD134. CD69 is an early activation marker found on B and T lymphocytes, NK cells and granulocytes. CD25 is an IL-2 receptor and is a marker for activated T cells and B cells. CD4 is a TCR coreceptor and is marker for thymoctes, T_H1-and T_H2-type T cells, monocytes, and macrophages. CD8 is also a TCR coreceptor and is marker for cytotoxic T cells. CD134 is expressed only in activated $CD4^+$ T cells.

[0050] Cell surface markers for negatively selecting for activated T cells include, but are not limited to, CD36, CD40, and CD44. CD28 acts as a stimulatory T-cell activation pathway independent of the T-cell receptor pathway and is expressed on $CD4^+$ and $CD8^+$ cells. CD36 is a membrane glycoprotein and is a marker for platelets, monocytes and endothelial cells. CD40 is a marker for B cells, macrophages and dendritic cells. CD44 is a marker for macrophages and other phagocytic cells. Subsets of T cells may be isolated by using positive selection, negative selection, or a combination thereof for expression of cell surface gene products of helper T cells or cytotoxic T cells (e.g., CD4 vs. CD8).

[0051] Cytokines for identifying activated T cells of the present invention include, but are not limited to cytokines produced by T_H1-type T cells (cell-mediated response) and T_H2-type T cells (antibody response). Cytokines for identifying activated T_H1-type T cells include, but are not limited to, IL-2, gamma interferon (γIFN) and tissue

necrosis factor alpha (TNFα). Cytokines for identifying activated T_H2-type T cells include, but not limited to, IL-4, IL-5, IL-10 and IL-13. Subsets of T cells may also be isolated by using positive selection, negative selection, or a combination thereof for expression of cytokine gene products of helper T cells or cytotoxic T cells (e.g., γIFN vs. IL4).

[0052] An activated T_H1-type T cell specific for an antigen of interest may be isolated by identifying cells that express CD69, CD4, CD25, IL-2, IFNγ, TNFα, or a combination thereof. An activated T_H1-type T cell specific for an antigen of interest may also be isolated by identifying cells that express CD69 and CD4 together with IFNγ or TNFα. An activated T_H2-type T cell specific for an antigen of interest may be isolated by identifying cells that express CD69, CD4, IL-4, IL-5, IL-10, IL-13, or a combination thereof. A combination of an activated T_H1-type T cell and a T_H2-type T cell specific for an antigen of interest may be isolated by identifying cells that express CD69, CD4, CD25, IL-2, IFNγ, TNFα, or a combination thereof and cells that express CD69, CD4, IL-4, IL-5, IL-10, IL-13, or a combination thereof/

[0053] The gene products used for positive or negative selection of the activated T cells of the present invention may be identified by immunoselection techniques known to those in the art which utilize antibodies including, but not limited to, fluorescence activated cell sorting (FACS), magnetic cell sorting, panning, and chromatography. Immunoselection of two or more markers on activated T cells may be performed in one or more steps, wherein each step positively or negatively selects for one or more markers. When immunoselection of two or more markers is performed in one step using FACS, the two or more different antibodies may be labeled with different fluorophores.

[0054] Magnetic cell sorting may be performed using super-paramagnetic microbeads composed of iron oxide and a polysaccharide coat. Preferably the microbeads may be approximately 50 nanometers in diameter, and have a volume about one-millionth that of a typical mammalian cell. The microbeads are preferably small enough to remain in colloidal suspension, which permits rapid, efficient binding to cell surface antigens. The microbeads preferably do not interfere with flow cytometry, are biodegradable, and have negligible effects on cellular functions. The antibody coupling to the microbeads may be direct or indirect, via a second antibody to a ligand such as fluorescein.

[0055] The antibody may be of classes IgG, IgM, IgA, IgD, and IgE, or fragments or derivatives thereof, including Fab, $F(ab')_2$, Fd, and single chain antibodies, diabodies, bispecific antibodies, bifunctional antibodies and derivatives thereof. The antibody may be a monoclonal antibody, polyclonal antibody, affinity purified antibody, or mixtures thereof which exhibits sufficient binding specificity to an epitope of a gene product specific for activated T cells, or a sequence derived therefrom. The antibody may also be a chimeric antibody.

[0056] The antibody may be derivatized by the attachment of one or more chemical, peptide, or polypeptide moieties known in the art that allow the identification and/or selection of the activated T cell to which the antibody is bound. The antibody may be conjugated with a chemical moiety such as a fluorescent dye. An activated T cell bound by a fluorescently labeled antibody may be isolated using techniques including, but not limited to, fluorescence activated cell sorting (FACS). The antibody may also be conjugated with a magnetic particle, such as a paramagnetic microbead (Miltenyi Biotec, Germany). An activated T cell bound by a magnetically labeled antibody may be isolated using techniques including, but not limited to, magnetic cell sorting.

[0057] For cell-surface expressed gene products, the antibody may directly bind to the gene product and may be used for cell selection. For cell-surface gene products expressed at low concentrations, magnetofluorescent liposomes (Scheffold, *et al. Nature Med* 6:107-110, 2000) may be used for cell selection. At low levels of expression, conventional fluorescently labeled antibodies may not be sensitive enough to detect the presence of the cell surface expressed gene product. Fluorophore-containing liposomes may be conjugated to antibodies with the specificity of interest, thereby allowing detection of the cell surface expressed gene product.

[0058] For intracellular gene products, such as cytokines, the antibody may be used after permeabilizing the cells. Alternatively, to avoid killing the cells by permeabilization, the intracellular gene product if it is ultimately secreted from the cell may be detected as it is secreted through the cell membrane using a "catch" antibody on the cell surface. The catch antibody may be a double antibody that is specific for two different antigens: (i) the secreted gene product of interest and (ii) a cell surface protein. The cell surface protein may be any surface marker present on T cells, in particular, or lymphocytes, in general, (e.g., CD45). The catch antibody may first bind to the cell surface protein and then bind to the intracellular gene product of interest as it is secreted through the membrane, thereby retaining the gene product on

the cell surface. A labeled antibody specific for the captured gene product may then be used to bind to the captured gene product, which allows the selection of the activated T cell (Manz, *et al. Proc. Natl. Acad. Sci. USA* 92:1921-1925, 1995, incorporated herein by reference).

[0059] Certain forms of cytokines are also found expressed at low concentration on the cell surface. For example, γIFN is displayed at a low concentration on the cell surface with kinetics similar to those of intracellular γIFN expression (Assenmacher, *et al. Eur J. Immunol,* 1996, 26:263-267). For forms of cytokines expressed on the cell surface, conventional fluorescently labeled antibodies or fluorophore containing liposomes may be used for detecting the cytokine of interest. One of ordinary skill in the art will recognize other techniques for detecting and selecting extracellular and intracellular gene products specific for activated T cells.

[0060] The T cells isolated by the present invention may be enriched by at least 90% from whole blood. The T cells may also be enriched by at least 95% from whole blood. The T cells may also be enriched by at least 98% from whole blood. The T cells may also be isolated at least 99.5% from whole blood.

b. Isolated Monoclonal Antigen-Specific T Cells

[0061] In a second aspect, the present invention is directed to a T cell specific for an antigen of interest isolated by the method of the first aspect of the present invention.

c. Isolation of Polyclonal Antigen-Specific T Cells

[0062] In a third aspect, the present invention is directed to a method for isolating T cells that are specific for one or more antigens of interest. A sample comprising T cells is incubated with one or more antigens, which cause the activation of T cells specific for one or more antigens. T cells specific for one or more antigens may then be isolated as in the first aspect of the present invention.

[0063] The T cells may have a heterogeneous pattern of Vβ-Dβ-Jβ gene usage that express different TCRs which are each specific for an antigen of interest. The T cells may also have a heterogeneous pattern of Vβ-Dβ-Jβ gene usage that express different TCRs which are specific for more than one antigen of interest. As described below, T cells comprising a heterogeneous pattern of Vβ-Dβ-Jβ gene usage may be used to formulate a polyclonal T cell vaccine which may prevent epitope spreading in vaccinated patients.

d. Isolated Polyclonal Antigen-Specific T Cells

[0064] In a fourth aspect, the present invention is directed to T cells specific for one or more antigens of interest isolated by the method of the third aspect of the present invention.

3. Quantifying the Number of Antigen-Specific T cells

[0065] In a fifth aspect, the present invention is directed to a method of determining the relative frequency of T cells specific for one or more antigens of interest in a sample by determining the number of T cells isolated by the method of the first or third aspects of the present invention.

4. Diagnosing an Autoimmune Disease

[0066] In a sixth aspect of the present invention, a patient with an autoimmune disease may be diagnosed by obtaining a sample from a patient and isolating autoreactive T cells by the method of the first or third aspects of the present invention. The autoimmune disease may be diagnosed by comparing the level of autoreactive T cells in a patient to a control. The level of autoreactive T cells may be determined in accordance with the method of the fifth aspect of the present invention.

5. Monitoring the Progress of an Autoimmune Disease

[0067] In a seventh aspect of the present invention, an autoimmune disease may be monitored by determining the frequency of autoreactive T cells in a sample from a patient with an autoimmune disease in accordance with the fifth aspect of the present invention. The severity of symptoms of the autoimmune disease may correlate with the number of autoreactive T cells. In addition, an increase in the number of autoreactive T cells in the sample may be used as an indication to apply treatments intended to minimize the severity of the symptoms and/or treat the disease before the symptoms appear.

6. Producing a Vaccine for the Treatment of an Autoimmune Disease

[0068] In an eighth aspect of the present invention, a composition may be produced for treating an autoimmune disease by inactivating autoreactive T cells which have been isolated (and optionally expanded in culture as described herein) by the method of the first or third aspects of the present invention. The autoreactive T cells may be inactivated using a number of techniques known to those in the art including, but not

limited to, chemical inactivation or irradiation. The autoreactive T cells may be preserved either before or after inactivation using a number of techniques known to those in the art including, but not limited to, cryopreservation. As described below, the composition may be used as a vaccine to deplete autoreactive T cells in autoimmune patients.

[0069] The composition may be a pharmaceutical composition, which may be produced using methods well known in the art. Pharmaceutical compositions used as preclinical and clinical therapeutics in the treatment of disease or disorders may be produced by those of skill, employing accepted principles of diagnosis and treatment. Such principles are known in the art, and are set forth, for example, in Braunwald *et al.*, eds., Harrison's Principles of Internal Medicine, 11th Ed., McGraw-Hill, publisher, New York, N.Y. (1987), which is incorporated by reference herein. The pharmaceutical composition may be administered to any animal which may experience the beneficial effects of the composition. Animals receiving the pharmaceutical composition may be humans or other mammals.

a. Vaccine

[0070] In a ninth aspect, the present invention is drawn to a composition produced by the method of the eighth aspect of the present invention. The composition may be a vaccine, which may be used to deplete autoreactive T cells in autoimmune patients.

7. Treatment of an Autoimmune Disease

[0071] In a tenth aspect, an autoimmune disease may be treated in patients with autoreactive T cells by administering a composition according to the ninth aspect of the present invention. The composition may be a vaccine, which may lead to the depletion of autoreactive T cells in the patient.

[0072] A vaccine may comprise autoreactive T cells comprising homogeneous ("monoclonal") or heterogeneous ("polyclonal") patterns of Vβ-Dβ-Jβ gene usage. Clinical studies indicate that autoimmune patients receiving autologous monoclonal T cell vaccination may show a gradual decline in the immunity against myelin-reactive T cells. In some cases, the reappearing autoreactive T cells may originate from different clonal populations, suggesting that myelin-reactive T cells may undergo clonal shift or epitope spreading potentially associated with the ongoing disease process. Clonal shift or epitope spreading may be a problem in autoimmune diseases mediated by autoreactive T cells. A vaccine comprising polyclonal autoreactive T

cells capable of depleting multiple populations of autoreactive T cells may avoid problems with clonal shift or epitope spreading.

[0073] The composition may be a pharmaceutical composition, which is administered by any means that achieve their intended purpose. For example, administration may be by parenteral, subcutaneous, intravenous, intraarterial, intradermal, intramuscular, intraperitoneal, transdermal, transmucosal, intracerebral, intrathecal, or intraventricular routes. Alternatively, or concurrently, administration may be by the oral route. The pharmaceutical compositions may be administered parenterally by bolus injection or by gradual perfusion over time.

[0074] The dosage administered may be dependent upon the age, sex, health, and weight of the recipient, kind of concurrent treatment, if any, frequency of treatment, and the nature of the effect desired. The dose ranges for the administration of the pharmaceutical compositions may be large enough to produce the desired effect, whereby, for example, autoreactive T cells are depleted, as measured by the seventh aspect of the present invention, is achieved, and the autoimmune disease is significantly prevented, suppressed, or treated. The doses may not be so large as to cause adverse side effects, such as unwanted cross reactions, generalized immunosuppression, anaphylactic reactions and the like.

[0075] The pharmaceutical compositions may further comprise suitable pharmaceutically acceptable carriers comprising excipients and auxiliaries which may facilitate processing of the active compositions into preparations which can be used pharmaceutically. Additives to the pharmaceutical compositions may include the inclusion of an adjuvant, such as alum, chitosan, or other adjuvants known in the art. (See, for example, Warren et al., Ann. Rev. Immunol. 4:369-388 (1986); Chedid, L., Feder. Proc. 45:2531-2560 (1986), which are incorporated herein by reference). The pharmaceutical compositions may also further comprise liposomes to enhance delivery or bioactivity, using methods and compounds known in the art.

[0076] Suitable formulations for parenteral administration include aqueous solutions of the inactivated autoreactive T cells, for example, water-soluble salts in aqueous solution. In addition, oil suspensions comprising inactivated autoreactive T cells may be administered. Suitable lipophilic solvents or vehicles include fatty oils, for example, sesame oil, or synthetic fatty acid esters, for example, ethyl oleate or triglycerides. Aqueous injection suspensions may contain substances which increase

the viscosity of the suspension include, for example, sodium carboxymethyl cellulose, sorbitol, and/or dextran. The suspension may also contain stabilizers.

[0077] The inactivated autoreactive T cells may be formulated using conventional pharmaceutically acceptable parenteral vehicles for administration by injection. These vehicles may be nontoxic and therapeutic, and a number of formulations are set forth in Remington's Pharmaceutical Sciences, (supra). Nonlimiting examples of excipients are water, saline, Ringer's solution, dextrose solution and Hank's balanced salt solution. Pharmaceutical compositions may also contain minor amounts of additives such as substances that maintain isotonicity, physiological pH, and stability.

[0078] The inactivated autoreactive T cells may be formulated at total cell concentrations including from about $5x10^2$ cells/ml to about $1x10^9$ cells /ml. Preferred doses of the inactivated autoreactive T cells for use in preventing, suppressing, or treating an autoimmune disease may be in the range of about $2x10^6$ cells to about $9x10^7$ cells.

8. Determination of TCR Repertoire

[0079] In an eleventh aspect, the present invention is drawn to a method of determining the repertoire of nucleic acids encoding one or more T cell receptors, or a portion thereof, in an autoimmune patient by amplifying nucleic acids encoding one or more T cell receptors from T cells isolated by the first or third aspects of the present invention, wherein said amplification is performed using a primer pair. The first primer of the primer pair may be an oligonucleotide of about 15 to 30 nucleotides in length that hybridizes to a nucleic acid comprising the variable region of the TCR gene. The second primer of the primer pair may be an oligonucleotide of about 15 to 30 nucleotides in length that hybridizes to a nucleic acid comprising the constant region of the TCR gene. The primer pair may be used to amplify a nucleic acid that hybridizes to the Vβ-Dβ-Jβ region of the TCR gene.

[0080] Nucleic acids encoding one or more T cell receptors from T cells (the "Target Sequence") or a fragment thereof may be amplified from a sample by the polymerase chain reaction (PCR) using any particular PCR technique or equipment known in the art. For example, PCR amplification may follow a procedure wherein a reaction mixture is prepared that contains the following ingredients: 5 μL 10xPCR buffer II (100 mM Tris-HCl, pH 8.3, 500 mM KCl), 3 μL 25 mM $MgCl_2$, 1 μL 10 mM dNTP mix, 0.3 μL Taq polymerase (5 U/μL) (AmpliTaq Gold, Perkin Elmer, Norwalk,

Conn.), 30 pmol of a first primer, 30 pmol of a second primer, and 1 μL of sample DNA. The polymerase may be stable at temperatures of at least 95°C, have a processivity of 50-60 and have an extension rate of greater than 50 nucleotides per minute.

[0081] The PCR reaction may be performed with an amplification profile of 1 min at 95°C (denaturation), 20 sec at 56°C (annealing), and 40 sec at 72°C (extension) for a total of 40 cycles. Before the first cycle begins, the reaction mixture may undergo an initial denaturation for a period of about 5 min to 15 min. Similarly, after the final cycle is complete, the reaction mixture may undergo a final extension for a period of about 5 min to 10 min. Certain PCR reactions may work with as few as 15 to 20 cycles or as many as 50 cycles. Depending upon the specific PCR reaction, longer or shorter incubation times and higher or lower temperatures for each step of the amplification profile may be used.

[0082] The sample comprising the Target Sequence, may be a nucleic acid, such as genomic DNA, cDNA, DNA previously amplified by PCR, or any other form of DNA. The sample may be isolated, directly or indirectly, from any animal or human tissue comprising T cells, such as peripheral blood mononuclear cells (PBMC). Genomic DNA may be isolated directly from a tissue comprising T cells. cDNA may be isolated indirectly by reverse transcription of mRNA directly isolated from a tissue comprising T cells.

[0083] The ability to detect the Target Sequence may be enhanced by isolating the sample DNA indirectly by amplification of genomic DNA, cDNA, or any other form of DNA, by a two-step PCR reaction. For example, a first PCR amplification reaction may be performed to amplify a preliminary fragment that is larger than, and comprises, a fragment to which the first and second primers are capable of selectively binding on opposite strands. A second PCR amplification reaction may then be performed, using the preliminary fragment as a template with the first and second primers, to amplify a fragment comprising the Target Sequence. If either the first or second primer is used in the first PCR reaction to amplify the preliminary fragment, the second PCR reaction is "semi-nested." If neither the first or second primer is used in the first PCR reaction to amplify the preliminary fragment, the second PCR reaction is "nested."

[0084] In an exemplary two-step PCR reaction, one or more nucleic acids encoding one or more T cell receptors from T cells may be amplified by performing a first PCR reaction using a first preliminary primer that anneals to the Vβ region of the TCR gene and a second preliminary primer that anneals to the Cβ region of the TCR gene, which amplifies a preliminary fragment that extends from Vβ through the Vβ-Dβ-Jβ junction to Cβ, followed by a second PCR reaction which may be nested or semi-nested. In light of the present disclosure, the skilled artisan will be able to select appropriate primers and reaction conditions for PCR amplification of the Target Sequence.

[0085] After amplification of the Target Sequence, the amplified product may be detected by a number of procedures. For example, an aliquot of amplification product may be loaded onto an electrophoresis gel, to which an electric field is applied to separate DNA molecules by size. In another method, an aliquot of amplification product may be loaded onto a gel stained with SYBR green, ethidium bromide, or another molecule that will bind to DNA and emit a detectable signal. A dried gel may contain a labeled oligonucleotide that hybridizes to the Target Sequence, from which an autoradiograph may be taken by exposing the gel to film.

[0086] The following examples are included to demonstrate preferred embodiments of the invention. It should be appreciated by those of skill in the art that the techniques disclosed in the examples which follow represent techniques discovered by the inventor to function well in the practice of the invention, and thus can be considered to constitute preferred modes for its practice. However, those of skill in the art should, in light of the present disclosure, appreciate that many changes can be made in the specific embodiments which are disclosed and still obtain a like or similar result without departing from the spirit and scope of the invention.

EXAMPLE 1

Isolation of Myelin-Reactive T Cells for T Cell Vaccination

1. Preparation of PBMC and the Primary Stimulation

[0087] Fresh blood specimens from MS patients and control patients were processed within 2 hours of collection. Alternatively, mononuclear cells may be obtained from the cerebrospinal fluid (CSFMCs) of MS patients. Peripheral blood mononuclear cells (PBMCs) were isolated from the whole blood by standard Ficoll gradient

separation method. Specifically, heparinized blood was diluted with Hanks balanced salt solution (HBSS) (1:1 blood/HBSS) and then slowly laid over the Ficoll-hypaque solution in a centrifuge tube and centrifuged for 20 minutes at 1800 rpm, 18°C to 25°C, with no brake. PBMCs were then washed by adding excess HBSS and centrifuged at 1700 rpm for 10 minutes at 18°C to 25°C. Purified PBMCs were washed three times in RPMI 1640 medium by centrifugation and subsequently resuspended in AIM V medium (Gibco, Grand Island, N.Y.). Cell number was counted and cells were plated onto 96-well U-bottomed culture plates at a density of 200,000 cells/well. All plates were labeled with patient number and patient initials. The cells were incubated at 37°C in the presence of synthetic peptides listed in Table 1 corresponding to the known immunodominant regions of three myelin proteins, myelin basic protein (MBP), proteolipid protein (PLP), and myelin oligodendrocyte glycoprotein (MOG) at a concentration of 20 μg/ml. Plates were placed in a CO_2 incubator at 37°C and visually inspected daily. Cells were cultured for 7-10 days without change of culture medium to selectively grow antigen-specific T cells.

Table 1 - Activating Peptides

Myelin Antigen Peptides	Amino Acid Sequences	
Myelin basic protein, peptide-1 (MBP-1)	ENPVVHFFKNIVTPRTP	SEQ ID NO. 1
Myelin basic protein, peptide-2 (MBP-2)	SKIFKLGGRDSRSGSPMARR	SEQ ID NO. 2
Proteolipid protein, peptide-3 (PLP-3)	LFCGCGHEALTGTEKLIETY	SEQ ID NO. 3
Proteolipid protein, peptide-4 (PLP-4)	WTTCQSIAFPSKTSASIGSL	SEQ ID NO. 4
Myelin oligodendrocyte glycoprotein, peptide-6 (MOG-6)	GQFRVIGPRHPIRALVG	SEQ ID NO. 5
Myelin oligodendrocyte glycoprotein, peptide-7 (MOG-7)	EVELPCRISPGKNATGMEVGW	SEQ ID NO. 6

2. Identification and Selection of Antigen-Specific T Cells

[0088] The cells described above are then selected for the expression of gene products indicative of activated T cells. See Section 2(a) above. A Cytokine Catch Reagent (Miltenyi Biotec) (as described above) is used in order to detect the intracellular cytokine γIFN or TNFα when ultimately excreted from the cell. Briefly, the Cytokine Catch Reagent (typically a bispecific antibody which binds to both the activated T cell marker and the secreted cytokine) is incubated first with the cells at 4-8° C in order to bind to the CD45 molecule on the cell surfaces or other activated T cell surface marker such as CD69. The cells with the bound Cytokine Catch Reagent are then incubated at 37° C for 45 minutes to allow the γIFN or TNFα within the cell to also bind to the Cytokine Catch Reagent as the cytokine is secreted from inside the cell

during this incubation period. γIFN or TNFα, now bound to the cell surface by the Cytokine Catch Reagent which is then detected using an antibody specific for cytokine of interest conjugated to the fluorochrome PE.

[0089] The cell surface molecules CD4 and CD69, are detected using antibodies conjugated to different fluorochromes. The $CD4^+$ cell population is selected first by gating and then, within this population, the "double-positive" (CD69 and IFNγ or CD69 and TNFα) stained cells are separated by FACS and collected aseptically.

[0090] The isolated myelin-reactive T cells are then directly expanded by stimulating with rIL-2, PHA, anti-CD3 or other general T cell mitogen in the presence of irradiated autologous PBMCs for 7-10 days. Myelin-reactive T cells lines are propagated in culture until the total cell number reached approximately 20 million.

EXAMPLE 2

Diagnosis of MS

[0091] Two to 100 ml of blood are collected from the patient and one or more synthetic peptides are added directly to the whole blood to prime, or stimulate, the T lymphocytes. The peptides correspond to the known immunodominant regions of three myelin proteins, myelin basic protein (MBP), proteolipid protein (PLP), and myelin oligodendrocyte glycoprotein (MOG). The blood is incubated with the peptides for 1 to 7 days to activate the myelin-specific T cells. At the end of this antigen-priming period, the cells are re-challenged with antigens in a short re-stimulation assay.

[0092] Myelin peptide-activated T cells are detected by permeabilizing the cell membrane with a detergent solution, washing the cells, then incubating with one or more staining antibodies to detect CD4 or CD69 molecules on the cell surface or IFNγ or TNFα intracellularly. The staining antibodies are conjugated to different fluorochromes so that they fluoresce at different wavelengths when excited by a 488 nanometer laser by FASC analysis. The population of $CD4^+$ T cells is selected first by using the $CD4^+$ cells for gating and then within this population, the cells that are immunoreactive with both antibodies (CD69 and γIFN or CD69 and TNFα) are identified. This population of "double-positive" myelin-reactive T cells has been shown to increase significantly in multiple sclerosis (MS) patients as compared to healthy controls in a similar study (Figure 1, MS patient, Figure 2, healthy control).

Using this method, the number of myelin-reactive T cells circulating in the blood of a patient may be determined before, during and after treatment to determine the effect of an MS therapy on the autoreactive T cell population. The endpoint may be determined as either the percentage of double-positive stained cells or as the absolute number of double-positive stained cells.

EXAMPLE 3

Diagnosis of MS Using Antibody-Conjugated Liposomes

[0093] Whole blood is obtained from a patient and stimulated with one or more synthetic peptides as described in Example 2. The blood is incubated with the peptides for 3 to 16 hours to activate the myelin-specific T cells. At the end of this antigen-priming period, the cells may be re-challenged with antigens in a short re-stimulation assay prior to staining with magnetofluorescent liposomes conjugated to antibodies against IFNγ,TNFα, or a combination thereof. The cells are also stained with an antibody to CD4 and/or CD69. The stained myelin-reactive T cells are detected as described in Example 2.

EXAMPLE 4

Determination of TCR Clonal Repertoire

[0094] The T cell receptor (TCR) clonal repertoire represented in a cell population may be analyzed by isolating out the double-positive stained cell population by cell sorting as described in Example 2 and Example 3. DNA is extracted from the isolated cells and used to perform quantitative polymerase chain reaction (PCR) assays using oligonucleotide primers specific for 25 known TCR variable beta chain (Vβ) gene families. This procedure yields information on the distribution of TCR Vβ gene usage and indicates the clonality of pathogenic T cell populations. This method may also be used to determine if clonal or epitopic shifting of the myelin-reactive T cell population is occurring in an MS patient.

EXAMPLE 5

The Depletion of Myelin-reactive T cells by T cell vaccination

[0095] Patients with relapsing-remitting (RR)-MS and secondary-progressive (SP)-MS received three subcutaneous injections of irradiated autologous myelin-reactive T cell clones isolated by direct expansion, with three additional injections 4, 12 and 20

weeks thereafter. Patients were monitored for changes in the precursor frequency of myelin-reactive T cells, rate of relapse, expanded disability status score (EDSS) and MRI lesion activities over a period of 24 months. The results were compared with pre-vaccination values in a self-paired manner. In addition, the clinical data of the placebo arms of RR-MS in the beta-interferon-1a clinical trial (Jacobs *et al.*, 1996) and SP-MS in a recent beta-IFN-1b study (European Study Group, Lancet, 352:1491-1497 (1998)) were included to provide natural history data of MS for comparison. The T cell frequency was either undetectable or substantially declined after vaccination at week 20. The results confirmed depletion of myelin-reactive T cells by T cell vaccination in patients with MS.

EXAMPLE 6

Vaccination of MS Patient Using Autologous Myelin-Reactive T Cells

[0096] The vaccination protocol is similar to that used in previous clinical studies (Zhang *et al.*, 1993, Medaer *et al.*, 1995). Briefly, myelin-reactive T cell clones prepared according to Example 1 are activated with phytohemagglutinin (PHA) (4 μg /ml) in the presence of irradiated PBMCs as a source of accessory cells. Cells are then cultured for 10 days in RPMI 1640 media supplemented with 10% heat-inactivated human AB serum and 100 units per mL of rIL-2. Activated myelin-reactive T cells are subsequently washed three times with sterile saline to remove residual PHA, rIL-2 and cell debris and finally resuspended in 2 ml of saline. After irradiation (10,000 rads, ^{137}Ce source), the cells are injected subcutaneously on two arms (1 ml/arm). The number of T cells used for vaccination range from 40 x 10^6 to 80 x 10^6 cells per injection and are chosen by an extrapolation of T cell doses effective in experimental animals on the basis of relative skin surface areas (Ben-Nun *et al.*, 1981). Each patient receives two subcutaneous injections followed by repeat injections at 4, 12 and 20 weeks.

[0097] Patients are then observed for time to onset of confirmed progression of disability, EDSS, rate of relapse and MRI lesion activities. The results are compared with the patient's own pre-treatment course as well as the placebo arms of two recent clinical trials in RR-MS and SP-MS patients, which serve as an estimate of the natural history of MS (Jacobs *et al.*, 1996), European Study Group, 1998). Time to progression is determined by an increase of at least 1.0 on the EDSS (Poser *et al.*, 1983) persisting for at least 2 months. On-study exacerbations are defined by the

appearance of new neurological symptoms or worsening of pre-existing neurological symptoms lasting for at least 48 hours, accompanied by objective change on neurological examination (worsening of at least 0.5 point on EDSS). Patients are instructed to report events between the scheduled regular visits, and are examined by a neurologist if symptoms suggested an exacerbation. Safety assessments included adverse events, vital signs and physical examinations at regular visits. The differences in the clinical variables in study patients before and after T cell vaccination are analyzed using the Wilcoxon's rank-sum test.

EXAMPLE 7

Alteration of Clinical Course of MS After Vaccination

[0098] Patients receive T-cell vaccinations prepared according to Example 1 with no adverse effects. The mean EDSS declines in patients with RR-MS over a period of 24 months after vaccination. By comparison, there is an increase of mean EDSS by 0.61 in the natural history of RR-MS (n=56) over the same period of observation, as was reported in a trial conducted using beta-IFN-1a trial (Jacobs *et al.*, 1996). In addition, the proportion of the patients that have either unchanged or improved EDSS is higher than that of the natural MS history. Few, if any, patients in the treated RR-MS group progress beyond EDSS of 2.0 within 24 months as compared to 18% of patients in the natural history of MS.

[0099] In the SP-MS cohort, mean EDSS progresses slower over a period of 24 months as compared to +0.6 recorded in the natural history of SP-MS (European Study Group, Lancet 1998; 352:1491-1497). Furthermore, estimation of time to confirmed progression using the Kaplan-Meier method shows considerable delay as compared to the natural history of MS patients (20% progression in 12 months for RR-MS and 9 months for SP-MS) (Jacobs *et al.*, Ann. Neurol, 1996; 39:285-294, European Study Group, 1998).

CLAIMS

What is claimed is:

1. A method for isolating one or more T cells specific for an antigen of interest, comprising:
   (a) incubating a sample comprising T cells with said antigen or a derivative thereof;
   (b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13.

2. The method of claim 1, wherein said antigen is a self-antigen.

3. The method of claim 2, wherein said self-antigen is selected from the group consisting of myelin basic protein, proteolipid protein, myelin oligodendrocyte glycoprotein, collagen type II peptides, heat shock protein, MAGE, PSA, CA125, GAD protein, and tumor associated antigen.

4. The method of claim 1, wherein said antigen is an immunodominant epitope of a self-antigen.

5. The method of claim 4, wherein said immunodominant epitope is selected from the group consisting of residues 83-99 of myelin basic protein and residues 151-170 of myelin basic protein.

6. The method of claim 1, wherein the cells expressing said first and said second markers are selected using antibodies to said first and second markers respectively, or optionally a bi-specific antibody which binds both first and second markers in combination with an antibody which binds said second marker.

7. The method of claim 6, wherein one or more of said antibodies is fluorescently labeled.

8. The method of claim 7, wherein said T cell is selected by fluorescent activated cell sorting.

9. The method of claim 6, wherein said first antibody is conjugated to a magnetic microbead.

10. The method of claim 9, wherein said T cell is selected by magnetic activated cell sorting

11. The method of claim 1, wherein said antigen is incubated with said sample for 1 to 7 days.

12. The method of claim 1, wherein said antigen is incubated with said sample for less than 1 day.

13. The method of claim 12, wherein said antigen is incubated with said sample for less than 16 hours.

14. The method of claim 13, wherein said antigen is incubated with said sample for less than 12 hours.

15. The method of claim 14, wherein said antigen is incubated with said sample for less than 8 hours.

16. The method of claim 15, wherein said antigen is incubated with said sample for less than 4 hours.

17. The method of claim 16, wherein said antigen is incubated with said sample for less than 2 hours.

18. A T cell isolated by the method of claim 1.

19. The method of claim 1 wherein said isolated T cells are T_H1 or T_H2 T cells or a combination thereof.

20. A method for quantifying the number of T cells in a sample, wherein said T cells are specific for one or more antigens of interest, comprising:

(a) incubating a sample comprising T cells with said antigen or a derivative thereof;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13; and

(c) determining the number of T cells selected by step (b).

21. A method for diagnosing an autoimmune disease in a patient, comprising:

(a) incubating a sample derived from said patient comprising T cells with one or more autoantigens involved in said disease;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers

selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13.

22. A method for monitoring an autoimmune disease in a patient, comprising:

(a) incubating a sample derived from said patient comprising T cells with one or more autoantigens;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13; and

(c) determining the number of autoreactive T cells selected by step (a).

23. A method for treating an autoimmune disease in a patient, comprising:

(a) incubating a sample derived from said patient comprising T cells with one or more autoantigens;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13;

(c) inactivating said selected autoreactive T cells; and

(d) administering said autoreactive T cells inactivated by step (b) to said patient.

24. A method for producing a composition for the treatment of an autoimmune disease in a patient, comprising:

(a) incubating a sample derived from said patient comprising T cells with one or more autoantigens;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13; and

(c) inactivating said autoreactive T cells.

25. The method of claims 23 or 24 further comprising expanding the number autoreactive T cells selected in step (b).

26. A composition for the treatment of a patient with an autoimmune disease produced by the method of claim 24 or 25.

27. A method for isolating a nucleic acid encoding a T cell receptor, or a portion thereof, wherein said T cell receptor is specific for an antigen of interest, comprising:

(a) incubating a sample comprising T cells with said antigen;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13; and

(c) amplifying said nucleic acid encoding a T cell receptor from a T cell isolated by step (b) using at least one first primer specific for the variable region of the T cell receptor gene and a second primer specific for the constant region of the T cell receptor gene.

28. A method for isolating one or more nucleic acids encoding one or more T cell receptors, or a portion thereof, wherein said one or more T cell receptors are specific for one or more antigens of interest, comprising:

(a) incubating a sample comprising T cells with said one or more antigens;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13; and

(c) amplifying said one or more nucleic acids encoding one or more T cell receptors from T cells isolated by step (b) using at least one first primer specific for the variable region of the T cell receptor gene and a second primer specific for the constant region of the T cell receptor gene.

29. A method for determining the repertoire of nucleic acids encoding one or more T cell receptors, or a portion thereof, in a patient, wherein said one or more T cell receptors are specific for one or more antigens of interest, comprising:

(a) incubating a sample derived from said patient comprising T cells with said one or more antigens;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13;

(c) amplifying said one or more nucleic acids encoding one or more T cell receptors from T cells isolated by step (b) using at least one first primer specific for the variable region of the T cell receptor gene and a second primer specific for the constant region of the T cell receptor gene; and

(d) determining the nucleotide sequence of said one or more nucleic acids amplified by step (c).

30. A method for determining the repertoire of nucleic acids encoding one or more T cell receptors, or a portion thereof, in an autoimmune patient, wherein said one or more T cell receptors are specific for one or more autoantigens of interest, comprising:

(a) incubating a sample derived from said autoimmune patient comprising T cells with said one or more autoantigens;

(b) selecting one or more T cells that express one or more first markers selected from the group consisting of CD69, CD4, CD25, CD36 and HLADR and one or more second markers selected from the group consisting of IL-2 IFNγ and TNFα IL5 IL-10 and IL-13;

(c) amplifying said one or more nucleic acids encoding one or more T cell receptors from T cells isolated by step (b)using at least one first primer specific for the variable region of the T cell receptor gene and a second primer specific for the constant region of the T cell receptor gene; and

(d) determining the nucleotide sequence of said one or more nucleic acids amplified by step (c).