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DESCRIPTION

[0001] The invention relates to an in vitro method for the obtention of a food- or auto-antigen specific Tr1 cell population from a leukocyte or a PBMC population, which comprises stimulating the PBMC or leukocyte population with the food- or auto-antigen, and recovering the food- or auto-antigen specific Tr1 cell population from the stimulated cell population. Preferably, the PBMC or leukocyte population is restimulated at least once with the same antigen after step (1), in the presence of IL-2 and at least one interleukin selected from the group consisting of IL-4 and IL-13. The in vitro method may further comprise a third step of expanding the recovered antigen-specific Tr1 cell population, advantageously by contacting them with feeder cells capable of expressing factors necessary for said expansion. Preferably, the feeder cells are recombinant insect feeder cells.

[0002] Among the T cell populations, there is now accumulating evidence for a novel functionally distinct subpopulation of T cells, called Tr1 regulatory cells or Tr1 cells. The inventors showed that T regulatory 1 (Tr1) cells could be used to treat inflammatory diseases (i.e. Crohn's disease (H. Groux et al. Nature 1997, 389, 737-742), skin inflammation (Foussat et al. 2003 J. Immunol. 171, 5018-5026), atherosclerosis (Mallat et al. Circulation 2003, 108, 1232-1237) or multiple sclerosis (Barrat et al. 2002, 195, 603-616). In all these models it was shown that anti-inflammatory Tr1 cells were directed against a specific antigen and that the delivery of that antigen, preferentially on the site of inflammation, was required to stimulate Tr1 cells to induce their anti-inflammatory functions. Therefore, in order to use Tr1 cells to treat human diseases one has to be able to isolate antigen-specific Tr1 cells. However this has proven to be very difficult.

[0003] The international patent application WO 02/092793 teaches the preparation of Tr1 cells by stimulating CD4⁺ T cells with mouse L cells transfected with HLA-II DR1 and CD58 (LFA3), selecting CD4⁺ CD25⁺ cells and expanding clones in presence of IL-2 and IL-4.

The international patent application WO96/27392 describes the activation of T cells using engineered insect feeder cells.

The US patent application US2002/090357 teaches the generation of IL-10 producing CD4⁺ T cells by stimulating CD4⁺ T cells with an ovalbumin peptide, vitamin D3, dexamethasone and anti-CD3/CD28 beads.

[0004] The inventors have also shown that Tr1 cells express specific surface markers and could be characterized by the coexpression of the CD3 and CD4 markers as well as CD49b expression and a high expression level of CD 18, and, where appropriate, by the demonstration of an over-expression of genes encoding the proteins CD4, PSGL-1, PECAM-1 and alpha V/beta3 (see the international patent application published with the number WO 2005/000344).

[0005] Surprisingly the inventors have observed that purified Tr1 cells isolated from human blood based on the expression of these markers (and consequently Tr1 cells present in a PBMC or leukocyte population) proliferated vigorously in response to food- or auto-antigens and that the proliferative response of these cells could be maintained by the stimulation using both IL-2 and IL-4 (IL for interleukin). This potential offers an important advantage over the prior art, since according to the common knowledge of the skilled person, it was previously necessary to firstly isolate antigen-specific naive T cells from a PBMC population, secondly to induce the differentiation of antigen-specific Tr1 cells, whereas it is now possible to obtain food- or auto-antigen specific Tr1 cells directly from a PBMC (or leukocyte) population. In the present invention, the in vitro method to obtain food- or auto-antigen specific Tr1 cells is simplified, and safety for the patients to whom these cells are administered is increased, since these cells have not changed in terms of quality.

[0006] Consequently, the subject matter of the present invention is an in vitro method for the obtention of a food- or auto-antigen specific Tr1 cell population from a human leukocyte population or a human peripheral blood mononuclear cell (PBMC) population, said method consisting of:

1. 1) stimulating the human PBMC or leukocyte population with the food- or auto-antigen,
2. 2) recovering the food- or auto-antigen specific Tr1 cell population from the stimulated cell population,

provided that said method does not comprise stimulating human peripheral blood lymphocytes with ovalbumin.

[0007] Leukocytes encompass several types of cells which are characterized by their importance, their distribution, their number, their lifetime and their potentiality. These types are the following : the polynuclear or granular leukocytes, among which one finds the eosinophilic, the neutrophilic and the basophilic leukocytes, and the mononuclear cells, or peripheral blood mononuclear cells (PBMCs), which are large white blood cells and consist in the cell types of the immune system (lymphocytes and monocytes). The leukocytes or the PBMCs can be separated from the peripheral blood by any method known to those skilled in the art. Advantageously, for the separation of the PBMCs, centrifugation may be used, preferably density gradient centrifugation, preferably discontinuous density gradient centrifugation. An alternative is the use of specific monoclonal antibodies. In certain

embodiments PBMC are typically isolated from the whole blood product by means of Ficoll-Hypaque, using standard procedures. In other embodiments the PBMCs are recovered by means of leukapheresis.

[0008] The term "antigen" in the expression "antigen-specific Tr1 cell population" refers to an immunogenic peptide. Immunogenic peptides are peptides that can bind to major histocompatibility complex (MHC) molecules of an individual and that are recognized by the T cell receptors of said individual.

[0009] The terms protein, polypeptide, peptide employed in the present application refer indifferently to a molecule formed by the union in a long chain of smaller elements, the amino acids.

[0010] The term "food-antigen" refers to an immunogenic peptide which comes from foodstuffs, such as food antigens of the following non-limiting list: bovine antigens such as lipocalin, Ca-binding SIOO, alpha-lactalbumin, betalactoglobulin, bovine serum albumin, immunoglobulin or caseins. Food-antigens may also be atlantic salmon antigens such as parvalbumin, chicken antigens such as ovomucoid, ovalbumin, Ag22, conalbumin, lysozyme or chicken serum albumin, shrimp antigens such as tropomyosin, wheat antigens such as agglutinin or omega-5 gliadin, celery antigens such as celery profilin, carrot antigens such as carrot profilin, apple antigens such as thaumatin, apple lipid transfer protein, apple profilin, pear antigens such as pear profilin, isoflavone reductase, avocado antigens such as endochitinase, apricot antigens such as apricot lipid transfer protein, peach antigens such as peach lipid transfer protein or peach profilin, soybean antigens such as HPS, soybean profilin or (SAM22) PR-10 prot.

[0011] The term "auto-antigen" refers to an immunogenic peptide derived from a protein of said individual. It may be, by way of example, an auto-antigen of the following non-limiting list: acetylcholine receptor, actin, adenin nucleotide translocator, B-adrenoreceptor, aromatic L-amino acid decarboxylase, asialoglycoprotein receptor, bactericidal/permeability increasing protein (BPI), calcium sensing receptor, cholesterol side chain cleavage enzyme, collagen type N ay-chain, cytochrome P450 2D6, desmin, desmoglein-1, desmoglein-3, F-actin, GM- gangliosides, glutamate decarboxylase, glutamate receptor, H/K ATPase, 17- α -hydroxylase, 21-hydroxylase, IA-2 (ICAS12), insulin, insulin receptor, intrinsic factor type 1, leucocyte function antigen 1, myelin associated glycoprotein, myelin basic protein, myelin oligodendrocyte protein, myosin, P80-coilin, pyruvate deshydrogenase complex E2 (PDC-E2), sodium iodide symporter, SOX-10, thyroid and eye muscle shared protein, thyroglobulin, thyroid peroxidase, thyrotropin receptor, tissue transglutaminase, transcription coactivator p75, tryptophan hydroxylase, tyrosinase, tyrosine hydroxylase, ACTH, aminoacyl- tRNA-hystidyl synthetase, cardiolipin, carbonic anhydrase II, cebtromere associated proteins, DNA-dependant nucleosome-stimulated ATPase, fibrillarlin, fibronectin, glucose 6 phosphate isomerase, beta 2-glycoprotein 1, golgin (95, 97, 160, 180), heat shock proteins, hemidesmosomal protein 180, histone H2A, H2B, keratin, IgE receptor, Ku-DNA protein kinase, Ku-nucleoprotein, La phosphoprotein, myeloperoxidase, proteinase 3, RNA polymerase 1-111, signal recognition protein, topoisomerase I, tubulin, vimenscin, myelin associated oligodendrocyte basic protein (MOBP), proteolipid protein, oligodendrocyte specific protein (OSP/Claudin 11), cyclic nucleotide 3'phosphodiesterase (CNPase), BP antigen 1 (BPAG1-e), transaldolase (TAL), human mitochondrial autoantigens PDC-E2 (Novo 1 and 2), OGDC-E2 (Novo 3), and BCOADC-E2 (Novo 4), bullous pemphigoid (BP)180, laminin 5 (LN5), DEAD-box protein 48 (DDX48) or insulinoma-associated antigen-2.

[0012] Antigens such as bacterial or virus antigens are excluded from the expression "food-or auto-antigen".

[0013] The food- or auto-antigen, which is mostly composed of a sequence of amino-acids, may be synthesized by the usual techniques, such as the Fmoc method, if the sequence of amino-acids is known, or by known recombinant DNA technologies (see Sambrook et al. (Molecular Cloning: A Laboratory Manual, 2nd Edition, Cold Spring Harbor Laboratory press (1989)). Some food-or auto- antigens are also commercially available (Sigma, L'Isle d'Abeau, France). The food- or auto-antigen maybe also extracted.

[0014] Preferably, the food- or auto-antigen specific Tr1 cell population is obtained from a human PBMC population.

[0015] More preferably, the PBMC or leukocyte population is re-stimulated at least once with the same antigen after step (1), in the presence of interleukin-2 (IL-2) and at least one interleukin selected from the group consisting ofinterleukin-4 (IL-4) and interleukin-13 (IL-13).

The frequency of food- or auto-antigen stimulation may be at least once, preferably once a week, over a few weeks (usually about three), or several times at intervals of five to twelve days. Multiple stimulations can be performed by exchanging a portion of the culture supernatant with the same amount of fresh PBMC or leukocyte culture medium containing the antigen.

The IL-2 and IL-4 used for re-stimulation of the PBMC or leukocyte population may be synthesized or recombinant interleukins, and the skilled person is with wide experience of methods to obtain such interleukins (see for example Sambrook et al. (Molecular Cloning: A Laboratory Manual, 2nd Edition, Cold Spring Harbor Laboratory press (1989)). IL-2 and IL-4 can be purchased from

different sources, such as R&D Systems and Peptotech.

[0016] Preferably, the food- or auto-antigen is a recombinant or a synthesized antigen.

[0017] More preferably, the food-antigen is selected from the group comprising casein, soya protein, fragments, variants and mixtures thereof.

[0018] The term "variant" of the food- or auto-antigen refers herein to an antigen that is almost identical to the natural antigen and which shares the same biological activity. The minimal difference between the natural antigen and its variant may lie for example in an amino-acid substitution, deletion, and/or addition. Such variants may contain for example conservative amino acid substitutions in which amino acid residues are replaced with amino acid residues having a similar side chain. Families of amino acid residues having similar side chains have been defined in the art, including basic side chains (e.g., lysine, arginine, histidine), acidic side chains (e.g., aspartic acid, glutamic acid), uncharged polar side chains (e.g., glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine), nonpolar side chains (e.g., alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan), beta.-branched side chains (e.g., threonine, valine, isoleucine) and aromatic side chains (e.g., tyrosine, phenylalanine, tryptophan, histidine).

[0019] Most preferably, the food-antigen is selected from the group comprising bovin alpha S1-casein of sequence SEQ ID N°24, bovin beta-casein of sequence SEQ ID N°25, and sequences having at least 70 %, preferably 75, 77, 80, 82, 85, 87, 90, 92, 95, 96, 97, 98, 99 % of identity with one of the sequences SEQ ID N°24 and SEQ ID N°25.

[0020] In another preferred embodiment, the auto-antigen is selected from the group comprising insulin, myelin basic protein, fragments, variants and mixtures thereof.

[0021] The expression "stimulating the human PBMC or leukocyte population with the food-or auto-antigen" as used herein means to add the antigen to the human PBMC or leukocyte population and culture to react with T cells of said PBMC or leukocyte population. To produce a population of food- or auto-antigen specific Tr1 cells, the human PBMC or leukocyte population is contacted with an antigen according to the present invention in a form suitable to trigger a primary activation signal in the T cells of said PBMC or leukocyte population, that is to say the antigen is presented to the PBMC or leukocyte population such that a signal is triggered in the T cells through the CD3/TCR complex. For example, the antigen can be presented to the PBMCs or leukocytes in a soluble form (either directly to form complexes with the MHC molecules expressed by the PBMCs or leukocytes or the antigen can be coupled either to a soluble, a polymeric or a surface (plastic, ...) bound form of MHC molecules) or by an antigen presenting cell (APC) in conduction with an MHC molecule. An antigen presenting cell (APC), such as a B cell, macrophage, monocyte, dendritic cell, Langerhans cell, or other cell which can present antigen to the T cells of said PBMC or leukocyte population, can be incubated with the PBMCs or leukocytes in the presence of the antigen (for example a soluble antigen) such that the antigen presenting cell presents the antigen to the PBMCs or leukocytes. Alternatively, the APCs can be preincubated with the antigen before being added to the PBMCs or leukocytes. Alternatively, a cell expressing the food- or auto-antigen can be incubated with the PBMC or leukocyte population.

[0022] Preferably, the stimulation of the human PBMC or leukocyte population is performed in the wells of a microplate, a cell culture flask or a cell culture bag. The PBMC or leukocyte culture media which may be used are very well known by the skilled person: for example, the PBMCs or leukocytes may be stimulated in an RPMI medium supplemented with human serum or with X-vivo 15 (Cambrex).

[0023] Advantageously, the PBMC population stimulated at step (1) contains from $0.01 \cdot 10^6$ to $100 \cdot 10^6$ cells/mL, preferably from $0.2 \cdot 10^6$ to $5 \cdot 10^6$ cells/mL, more preferably from $0.1 \cdot 10^6$ to $3 \cdot 10^6$ cells/mL, even more preferably from $0.5 \cdot 10^6$ to $2.5 \cdot 10^6$ cells/mL, and most preferably from 10^6 to $2 \cdot 10^6$ cells/mL.

[0024] More advantageously, the food- or auto-antigen used for stimulation of the PBMC population at step (1) is in a soluble form from 0.1 µg/mL to 5 mg/mL preferably from 1 to 200 µg/mL.

[0025] It is however known from the man skilled in the art that the specific quantity of the food- or auto-antigen used for stimulation of the human PBMC or leukocyte population depends on which food- or auto-antigen is used.

[0026] In another particular embodiment, the human PBMC or leukocyte population is incubated, before stimulation at step (1), with a cell division fluorescent marker allowing to determine, by cytofluorometry, that when the fluorescence intensity of the stimulated cell population is at least twice lower than the fluorescence intensity of the human PBMC or leukocyte population, that

cell division has occurred in said stimulated cell population, and that said stimulated cell population which is recovered at step (2) is the antigen-specific Tr1 cell population.

Such a method, which allows to monitor cell division using fluorescent markers, is well known by the man skilled in the art and is very well appropriate for use at step (2) of recovering the antigen-specific Tr1 cell population, since the stimulated cell population whose fluorescence intensity is at least twice lower than the fluorescence intensity of the PBMC or leukocyte population, comprises the food or auto-antigen specific Tr1 cell population. Advantageously, the stimulated cell population whose fluorescence intensity is at least twice lower than the fluorescence intensity of the PBMC or leukocyte population, is the food or auto- antigen specific Tr1 cell population.

[0027] Preferably, the cell division fluorescent marker is the carboxyfluorescein diacetate succinimidyl ester (CFSE) marker, the oregon green 488 carboxylic acid diacetate (Carboxy-DFFDA SE) marker or the PKH26 (from the discoverer, Paul Karl Horan, PKH) marker, all being among others commercially available at Invitrogen.

[0028] The step (2) of recovering the food- or auto-antigen specific Tr1 cell population, can be performed by various methods well known by the skilled person. For example, Tr1 cells can be identified and/or purified by Elisa, flow cytometry, immunoaffinity chromatography with labelled antibodies directed against said Tr1 cell markers, for example with:

APC-conjugated anti-CD4 (RPA-T4) - Becton Dickinson (APC for allophycocyanine)

PC5- conjugated anti-CD3 (UCHT-1) - Caltag (PC5 for phycoerythrine-cyanine 5) PE-conjugated anti-CD18 (6.7) - Becton Dickinson (PE for phycoerythrine)

FITC- conjugated anti-CD49b (AK-7) - Becton Dickinson or PE-labeled mouse anti-human CD49b (12F1-H6) (FITC for fluoresceine- isothiocyanate).

Specific Tr1 cell markers are now well known by the skilled person, and are sufficiently described in the international patent application WO 2005/000344. Thus, in a preferred embodiment, the antigen-specific Tr1 cell population is recovered at step (2) by cytofluorometry using fluorescent labelled antibodies directed against proteins present at the surface of the cells of said antigen-specific Tr1 cell population.

[0029] ELISA tests and intracellular staining may also be used to measure IL-4, IL-10, and IFN- γ expression and to identify the Tr1 cells through their cytokine expression profile. Such methods are usually employed by the skilled person. For example, the supernatant obtained after step (1) of stimulation may be contacted with NIP-labelled antibodies directed against IL-4, IL-10 and IFN- γ expression (NIP for (4-hydroxy-5-iodo-3-nitrophenyl) acetyl (NIP), followed by peroxidase-labelled anti-NIP antibody and ABTS addition (ABTS for 2,2'-azino-di (3-ethyl-benzthiazoline-6-sulfonate) (from R&D Systems, Minneapolis, MN, and Chiron Corp., Emmerlyville, CA).

[0030] Preferably, the antigen-specific Tr1 cell population is recovered at step (2) by a cloning technique, such as advantageously by limiting dilution. Such methods are well known from the skilled person and will not be further disclosed in the present description.

[0031] It has to be envisaged that these methods of recovery of the antigen-specific Tr1 cell population may be employed alone or in combination. For example, the "CFSE method" may be used in combination with the cytofluorometry, or with the cloning limiting dilution technique. It is also possible to use the cytofluorometry followed by a cloning technique.

[0032] The present invention also relates to an in vitro method for the obtention of a food- or auto-antigen specific Tr1 cell population from a human leukocyte population or a human peripheral blood mononuclear cell (PBMC) population, said method comprising

1. a) recovering the food- or auto-antigen specific Tr1 cell population of step (2) of the method as described hereinabove, and
2. b) expanding the antigen-specific Tr1 cell population recovered at step (2) in a culture medium Mp.

[0033] The culture medium Mp may be of any kind, provided that it is appropriate for said antigen-specific Tr1 cell population, and will be easily selected by the skilled person (Schneider's medium, serum free media,...).

[0034] In the present application, the terms "expansion", "proliferation" and "growth" may be employed in an interchangeable way and refer to the increasing number of cells in a cell population. Preferably, the antigen-specific Tr1 cell population is expanded

exponentially.

[0035] Advantageously, the step (b) of expanding the antigen-specific Tr1 cell population consists in contacting said antigen specific Tr1 cell population with CD3+CD28 beads (for example purchased from Dynal, Oslo, Norway) in the presence of IL-2 and IL-4.

[0036] The present invention thus also relates to an in vitro method for the obtention of a food-or auto-antigen specific Tr1 cell population from a human leukocyte population or a human peripheral blood mononuclear cell (PBMC) population, said method comprising

1. a) recovering the food- or auto-antigen specific Tr1 cell population of step 2 of the method as described hereinabove, and
2. b) expanding the antigen-specific Tr1 cell population recovered at step (2) by contacting said antigen-specific Tr1 cell population with CD3+CD28 beads in the presence of IL-2 and IL-4.

[0037] In a particularly advantageous embodiment, the step (b) of expanding the antigen-specific Tr1 cell population requires the presence of a group of recombinant factors in the culture medium Mp, said expanding step comprising:

1. a) cultivating at a temperature T1 in a culture medium Mf, feeder cells capable of expressing a group of recombinant factors which interact with the following cell surface proteins of the antigen specific Tr1 cell population to be expanded:
 - the CD3/TCR protein complex
 - the CD28 protein,
 - the CD2 protein,
 - the interleukin-2 (IL-2) receptor, and
 - the interleukin-4 (IL-4 receptor),such T1 allowing the proliferation of said feeder cells,
2. b) contacting the feeder cells obtained at step (a) cleared or not of their culture medium Mf, with the antigen-specific Tr1 cell population contained in the culture medium Mp, wherein said culture medium Mp does not initially contain the group of factors, in order to obtain a mixture containing the antigen-specific Tr1 cell population, feeder cells and the culture medium Mp,
3. c) cultivating the mixture obtained at step (b) containing the factors of the group which are expressed by the feeder cells in the culture medium Mp, wherein said step (c) of cultivating is carried out at a temperature T2 which is at least about 35°C, such that:
 - the antigen-specific Tr1 cell population proliferates, and
 - the feeder cells do not proliferate,and wherein the antigen-specific Tr1 cell population is expanded,
4. d) recovering the antigen-specific Tr1 cell population so expanded.

[0038] The ratio [feeder cells: antigen-specific Tr1 cell population] is indifferent when adding the feeder cells to the antigen-specific Tr1 cell population (step (b)). Advantageously, this ratio may be [1:1].

[0039] Feeder cells may be of any type, provided that they do not proliferate at the culture temperature of the antigen-specific Tr1 cell population T2, which is at least about 35°C.

[0040] The expression "at least about 35°C" means that the temperature may vary from 0.1oc below 35°C (from 34.9°C to 35°C). The skilled person is anyway aware of such minimal variations of temperature.

[0041] The skilled person who is with wide experience of cell culture, knows the specific conditions to be used, in particular the optimal culture temperatures T₁ and T₂ of each of feeder cell population and antigen-specific Tr1 cell population. The culture medium Mf may be of any kind, provided that it is appropriate for said feeder cell type, and will be easily selected by the skilled person (Schneider's medium, ...).

[0042] It has to be considered that the step (b) of contacting the feeder cells with the antigen-specific Tr1 cell population, and the step (c) of cultivating the mixture at the temperature T₂, are usually simultaneous steps: before contacting, the feeder cells and the antigen-specific Tr1 cell population are cultivated separately, respectively one at the temperature T₁ in the culture

medium M_f and the other at the temperature T_2 in the culture medium M_p . Then, the feeder cells "alone", or the culture medium M_f containing the feeder cells, is/are contacted with the antigen-specific Tr1 cell population which is present in its culture medium M_p and which is being cultivated at the temperature T_2 . Consequently, the feeder cells pass immediately from the temperature T_1 to the temperature T_2 and stop to proliferate, unlike the antigen-specific Tr1 cell population, which is expanded thanks to the group of factors which are expressed by the feeder cells.

[0043] It is possible to maintain during a long time in vitro exponential growth of the antigen-specific Tr1 cell population, such as at least two or three months, by recultivating feeder cells regularly, for example every week, with said antigen-specific Tr1 cell population.

[0044] More advantageously, the feeder cells die during step (c) because of the temperature T_2 which is no more appropriate for feeder cell culture. Most advantageously, the cell membrane fragments of the feeder cells that result from death of said cells are eliminated at step (d).

[0045] After a sufficient time of cultivating the antigen-specific Tr1 cell population at step (c) such as preferably several hours, the obtained culture medium M_p is composed of a mixture of the antigen-specific Tr1 cell population, viable feeder cells and optionally cell membrane fragments of the feeder cells, and the expanded antigen-specific Tr1 cell population has to be recovered at step (d). Such a recovery can be made by separating the antigen-specific Tr1 cell population from the viable feeder cells and optionally said cell membrane fragments using any appropriate separation method well known by the man skilled in the art, such as for example flow cytometry using a specific labelled ligand capable to bind at the surface of the feeder cells or a cell surface protein of the antigen-specific Tr1 cell population. Other methods may also be employed, such as washing methods and/or centrifugation such as density gradient centrifugation using separation media like Ficoll®, such a centrifugation being an appropriate method for eliminating cell membrane fragments.

[0046] It has to be noted that the elimination of the cell membrane fragments of the feeder cells is not compulsory but recommended, all the more when the expanded antigen-specific Tr1 cell population is intended to be administered to mammals. Otherwise, there is a risk that said expanded antigen-specific Tr1 cell population is contaminated.

[0047] Advantageously, the group of factors comprise factors anchored to the cell membrane of the feeder cells and factors secreted by said feeder cells.

[0048] When the feeder cells are cultivated at step (a), they express some factors of the group at their cell membrane surface and some other factors in the culture medium M_f . At the step (b) of contacting, the "membrane factors" are already anchored to the feeder cell membrane, but the "secreted factors" may be eliminated if the feeder cells are previously cleared of their culture medium M_f . Anyway, both of the "membrane factors" and the "secreted factors" are expressed by the feeder cells at step (c), even if the feeder cells no more proliferate, and until death of said feeder cells. It is even possible that the "membrane factors" anchored to the cell membrane fragments of the dead feeder cells still play a role in the production of the antigen-specific Tr1 cell population.

[0049] The antigen-specific Tr1 cell population which is expanded has cell surface proteins which are implicated in the cell signals allowing its expansion. Such cell surface proteins are activated thanks to specific ligands, or factors, which are provided in the present invention by the feeder cells: feeder cells express the group of factors allowing the expansion of the antigen-specific Tr1 cell population. The man skilled in the art knows which specific factors have to be expressed by the feeder cells such that these factors interact with a cell surface protein of the antigen-specific Tr1 cell population.

[0050] Even more preferably, the feeder cells are recombinant cells and contain heterologous nucleic acids encoding the factors of said group.

[0051] The expressions "recombinant cell" or "recombinant feeder cell" refer to the introduction in said cells of heterologous nucleic acids encoding the factors of the group. Such an introduction encompasses a variety of techniques useful for introduction of nucleic acids into feeder cells including electroporation, calcium-phosphate precipitation, DEAE-dextran treatment, lipofection, microinjection and infection with viral vectors. Such suitable methods are very well known by the skilled person, and can be found for example in Sambrook et al. (Molecular Cloning: A Laboratory Manual, 2nd Edition, Cold Spring Harbor Laboratory press (1989)).

[0052] The nucleic acids to be introduced may be, for example, DNA encompassing the genes encoding the factors susceptible to interact with cell surface proteins of the antigen-specific Tr1 cell population to be expanded, genomic DNA fragments, sense

strand RNA or recombinant expression vectors containing cDNA encoding such genes. The heterologous nucleic acids can encode the full length factors or alternatively it can encode peptidic fragments thereof that are sufficient to allow the production of the antigen-specific Tr1 cell population in accordance with the present invention, when introduced into the feeder cells. The nucleic acids can encode the natural ligands (co-stimulatory proteins) of the cell surface proteins of the antigen-specific Tr1 cell population, or fragments thereof, or modified forms of the ligands or fragments thereof. The invention is intended to include the use of fragments, mutants, or variants (e.g., modified forms) of the factors that retain the ability to enhance the expansion of the antigen-specific Tr1 cell population. A "variant" of a factor means a protein that shares a significant homology with the natural ligand and which is implicated in expansion of the antigen-specific Tr1 cell population. The terms biologically active or biologically active form of a protein include forms of factors that are capable of effecting expansion of the antigen-specific Tr1 cell population. One skilled in the art can select such factor variants based on their ability to enhance cell expansion upon introduction of nucleic acids encoding the factors in the feeder cells. The ability of a specific variant of factor to enhance expansion of an antigen-specific Tr1 cell population can be readily determined, for example, by comparing the recombinant feeder cells with non-recombinant feeder cells by any known assay or method. Furthermore, it will be appreciated by those skilled in the art that changes in the primary amino acid sequence of the factors are likely to be tolerated without significantly impairing the ability of the proteins to allow the expansion of the antigen-specific Tr1 cell population. Accordingly, variants of the factors that have amino acid substitutions, deletions and/or additions as compared to the naturally occurring amino acid sequences of comparable native factors, yet still retain the functional activity of the natural forms of the factors as described herein are also encompassed by the invention. Such variants may contain for example conservative amino acid substitutions (see supra).

[0053] The nucleic acids are in a form suitable for the factor expression, said form containing all of the coding and regulatory sequences required for transcription and translation of a gene, which may include a promoter, an enhancer and a polyadenylation signal, and optionally a sequence necessary for transport of the factor to the surface of the feeder cells, including an N-terminal signal sequence. Regulatory sequences can also be selected to provide constitutive or inducible transcription. The expression of the factor at the surface of the feeder cell can be confirmed by immunofluorescent staining of the cells. For example, cells may be stained with a fluorescently labeled monoclonal antibody reactive against the co-stimulatory molecule or with a fluorescently labeled soluble receptor which binds the factor. The skilled person, who knows very well the factors to be expressed by the feeder cells, also knows appropriate monoclonal antibodies which recognize factors expressed by the feeder cells. Alternatively, labelled soluble ligand proteins which bind to the factors can be used to detect their expression on the feeder cell surface. The techniques and devices employed for detecting immunofluorescent stained cells are very well known by the skilled person; preferably, a fluorescence-activated cell sorter (FACS) is used for detection.

[0054] When the nucleic acid encoding a factor is operably linked to regulatory elements it is typically carried in a vector, including for example plasmids and viruses. Thus, a nucleic acid comprising a nucleotide sequence encoding a factor of the present invention operably linked to regulatory control elements, is also referred to herein as an "expression vector". Expression vectors will be chosen relative to the feeder cell type to be transformed. For example, when the feeder cells are drosophila insect feeder cells, drosophila constitutive vectors available for expression of proteins in cultured insect cells include the pAc series (Smith et al., (1983) Mol. Cell Biol. 3:2156-2165) and the pVL series (Lucklow, V. A., and Summers, M. D., (1989) Virology 170:31-39).

[0055] Moreover, it is preferred that the feeder cells do not have any intrinsic class I and/or II major histocompatibility complex (MHC) molecule at their surface. It means that these cells do not naturally express MHC molecules, unless they have been genetically transformed. The absence of these intrinsic class I and/or II MHC molecules at the surface of the feeder cells is crucial to avoid an allogeneic response between the feeder cells and the antigen-specific Tr1 cell population. As a result, the feeder cells of the present invention may be used to expand an antigen-specific Tr1 cell population from any donor in a short time period.

[0056] In a more particular embodiment, the feeder cells are cleared of their culture medium Mf at step (b).

[0057] Preferably, the feeder cells are insect feeder cells, with T₁ being inferior to T₂. Any appropriate insect feeder cell may be used in the present invention, provided that it fulfills the above mentioned conditions. It may be for example insect feeder cells of the Sf9 (among others deposited at the ATCC with the number CRL I711 or at the DSMZ with the number ACC I25, and marketed by BD Biosciences Pharmingen, US), Sf21 (among others deposited at the DSMZ with the number ACC I19, and also marketed by BD Biosciences Pharmingen, US) or the S2 cell line. Preferably, the insect feeder cells are from the S2 drosophila cell line. The S2 drosophila cell line is well known by the man skilled in the art, and has been widely disclosed in the prior art. The S2 drosophila cell line is commercially available (Invitrogen, France, etc...), and has been deposited in particular at the German collection of micro-organisms and culture cells DSMZ ("Deutsche Sammlung von Mikroorganismen und Zellkulturen") with the number ACC 130, and disclosed in Schneider, J Embryol Exp Morphol, 27:1972, 353; it has also been deposited at the American type culture collection ATCC with the number CRL I963. Preferably, the insect feeder cells are from the S2 drosophila cell line

deposited on March 25., 2005 at the National Collection of Micro-organisms Cultures (CNCM, Pasteur Institute, Paris) under the number I-3407.

[0058] A great advantage provided by the use of insect feeder cells when a mammal cell population, and here an antigen-specific Tr1 cell population, is to be expanded, is that (1) feeder cells and mammal cells do not proliferate at the same temperature (T_1 is inferior to T_2 and T_2 is at least about 35°C), and (2) mammal viruses do not proliferate in insect feeder cells, thus avoiding the possible virus contamination of the antigen-specific Tr1 cell population from the feeder cells.

[0059] Most preferably, the culture medium Mp is a serum-free culture medium. Media exempt from any biological contaminant, such as commercially available serum-free culture media (XVIVO-15 from BioWhittaker, Walkersville, MD ; AIM V medium from Invitrogen, etc...), are preferred.

[0060] Most preferably, the culture medium Mf is a serum-free culture medium. Media exempt from any biological contaminant, such as for example well known and commercially available serum-free culture media (Schneider's medium without serum marketed by BioWhittaker, Walkersville, MD GIBCO® serum-free insect cell culture media such as SFM marketed by Invitrogen, or Insectagro® serum-free media marketed by Krackeler Scientific Inc., US, etc...), are preferred in order to avoid subsequent contamination of the cell population P.

[0061] For the expansion of the antigen-specific Tr1 cell population, stimulation of the TCR/CD3 complex (TCR for T cell receptor and CD for cell differentiation antigen) is required for delivery of a primary activation signal in a T cell. An anti-CD3 monoclonal antibody can be used to activate a population of T cells via the TCR/CD3 complex, advantageously a modified anti-CD3 antibody, wherein the modification of the anti-CD3 antibody consists in the replacement of the intracytoplasmic domain with a transmembrane domain, such that said modified anti-CD3 antibody anchors to the cellular membrane of the feeder cells and interacts with the CD3/TCR protein complex of the T cells.

[0062] Furthermore, a number of proteins on the surface of T cells, interchangeably termed "co-stimulatory molecules" or "co-stimulators," have been implicated in regulating the transition of a resting T cell to blast transformation, and subsequent proliferation and differentiation. Thus, in addition to the primary activation signal provided through the TCR/CD3 complex, induction of T cell responses requires a second co-stimulatory signal. One co-stimulatory or accessory molecule, CD28, is believed to initiate or regulate a signal transduction pathway that is distinct from those stimulated by the TCR complex.

The factor interacting with the CD28 protein present at the surface of the antigen-specific Tr1 cells and which is expressed by the feeder cells, may be an anti-CD28 monoclonal antibody or a fragment thereof capable of crosslinking the CD28 molecule; in such a case, modification of the anti-CD28 monoclonal antibody can be envisaged by adding a transmembrane domain in order that it anchors to the cell surface of the feeder cells. Preferably, the natural ligand for CD28 is employed instead of the anti-CD28 monoclonal antibody, that is to say for example a member of the B7 family of proteins, such as B7-1 (CD80) and B7-2 (CD86) proteins.

Another co-stimulatory molecule, CD2, is implicated in the cell signals allowing expansion of the antigen-specific Tr1 cell population. Similarly, the factor expressed by the feeder cells which interacts with CD2 may be an anti-CD monoclonal antibody or a fragment thereof capable of crosslinking the CD2 molecule; modification of the anti-CD2 monoclonal antibody can be envisaged by adding a transmembrane domain for anchoring to the cell surface of the feeder cells. Preferably, the natural ligand for CD2 is employed instead of the anti-CD2 monoclonal antibody, that is to say the CD58 protein.

In addition to the factors which are anchored to the cell membrane of the feeder cells, factors which are secreted, such as interleukins, are also required for expansion of the antigen-specific Tr1 cell population. Among these interleukins are the IL-2, which interacts with the IL-2 receptor present at the surface of the antigen-specific Tr1 cells, and either the IL-4 or the IL-13, which interacts with the IL-4 receptor of the antigen-specific Tr1 cells.

[0063] Most advantageously, the group of recombinant factors comprise:

- the modified anti-CD3 antibody, wherein the modification of the anti-CD3 antibody consists in the replacement of the anti-CD3 intracytoplasmic domain of the anti-CD3 heavy chain with a transmembrane domain, said modified anti-CD3 antibody being anchored to the cell membrane of the feeder cells and being susceptible to interact with the CD3/TCR protein complex of the T cells, or a variant thereof,
- the CD80 or CD86 protein, preferably the CD80 protein, anchored to the cell membrane of the feeder cells, which is susceptible to interact with the CD28 protein of the T cells, or a variant thereof, and
- the CD58 protein anchored to the cell membrane of the feeder cells, which is susceptible to interact with the CD2 protein of the Tr1 cells, or a variant thereof,
- the IL-2 secreted by the feeder cells, which is susceptible to interact with the IL-2 receptor of the Tr1 cells, or a variant thereof, and

- an interleukin selected from the group comprising IL-4 and interleukin 13 (IL-13), preferably IL-4, said interleukin being secreted by the feeder cells and being susceptible to interact with the IL-4 receptor of the Tr1 cells, or a variant thereof.

[0064] Preferably, the transmembrane domain which replaces the intracytoplasmic domain of the anti-CD3 antibody heavy chain is the transmembrane domain of the platelet derived growth factor (PDGF) receptor.

[0065] Factors which are expressed by the feeder cells may be of any origin. Preferably, they are of the same origin than that of the PBMC or leukocyte population from which the antigen-specific Tr1 cell population is obtained. Therefore, preferably, the factors of said group are of human origin.

[0066] Preferably, the light chain of the modified anti-CD3 antibody is encoded by the heterologous nucleic acid of sequence SEQ ID N°1, or any nucleic acid having at least 70 % of identity with SEQ ID N°1, and wherein the heavy chain of the modified anti-CD3 antibody is encoded by the heterologous nucleic acid of sequence SEQ ID N°2, or any nucleic acid having at least 70 % of identity with SEQ ID N°2.

[0067] More preferably, the CD80 protein is encoded by the heterologous nucleic acid of sequence SEQ ID N°3, or any nucleic acid having at least 70 % of identity with SEQ ID N°3.

[0068] Advantageously, the CD86 protein is encoded by the heterologous nucleic acid of sequence SEQ ID N°4, or any nucleic acid having at least 70 % of identity with SEQ ID N°4.

[0069] Even more preferably, the CD58 protein is encoded by the heterologous nucleic acid of sequence SEQ ID N°6, or any nucleic acid having at least 70 % of identity with SEQ ID N°6.

[0070] In a preferred embodiment, the IL-2 is encoded by the heterologous nucleic acid of sequence SEQ ID N°5, or any nucleic acid having at least 70 % of identity with SEQ ID N°5.

[0071] Advantageously, the IL-4 is encoded by the heterologous nucleic acid of sequence SEQ ID N°7, or any nucleic acid having at least 70 % of identity with SEQ ID N°7.

[0072] More advantageously, the IL-13 is encoded by the heterologous nucleic acid of sequence SEQ ID N°8, or any nucleic acid having at least 70 % of identity with SEQ ID N°8.

[0073] The expression "nucleic acid molecule having at least 70 % of identity with SEQ ID No. X" refers to any sequence which has at least 70, 75, 80, 85, 90, 95 or 99% of identity with said sequence SEQ ID No. X.

[0074] Generally, after several hours of culture of the antigen-specific Tr1 cell population to be expanded such as 12 hours, preferably after 24 hours of culture, more preferably 48 hours, there is not any more viable feeder cells in the culture medium Mp. Advantageously, the expanded antigen-specific Tr1 cell population is recovered when all the feeder cells are dead, which allows firstly to obtain a larger expanded antigen-specific Tr1 cell population, and secondly to recover rapidly and easily the antigen-specific Tr1 cell population by eliminating the cell membrane fragments of the feeder cells, for example by washing methods and/or density gradient centrifugation, as disclosed above.

[0075] Thus, in a preferred embodiment, the antigen-specific Tr1 cell population so expanded is recovered at step (d) after having cultivated the antigen-specific Tr1 cell population at step (c) during at least 12 hours, advantageously 24 hours.

[0076] By percentage of identity between two nucleic acids (or nucleic acid sequences) or two proteic sequences in the present invention, it is meant a percentage of identical nucleotides or amino-acids between the two sequences to compare, obtained after the best alignment; this percentage is purely statistical, and the differences between the two sequences are randomly distributed and all along their length. The best alignment or optimal alignment is the alignment corresponding to the highest percentage of identity between the two sequences to compare, which is calculated such as herein after. The sequence comparisons between two nucleic acids or two proteic sequences are usually performed by comparing these sequences after their optimal alignment, said comparison being performed for one segment or for one "comparison window", to identify and compare local regions of sequence similarity. The optimal alignment of sequences for the comparison can be performed manually or by means of the algorithm of local homology of

[0077] Smith and Waterman (1981) (Ad. App. Math. 2:482), by means of the algorithm of local homology of Needleman and Wunsch (1970) (J. Mol. Biol. 48:443), by means of the similarity research method of Pearson and Lipman (1988) (Proc. Natl. Acad. Sci. USA 85:2444), by means of computer softwares using these algorithms (GAP, BESTFIT, FASTA and TFASTA in the Wisconsin Genetics Software Package, Genetics Computer Group, 575 Science Dr., Madison, WI). The percentage of identity between two nucleic acid sequences or two proteic sequences is determined by comparing these two aligned sequences in an optimal manner with a "comparison window" in which the region of the nucleic acid sequence or proteic sequence to compare may comprise additions or deletions with regard the sequence of reference for an optimal alignment between these two sequences. The percentage of identity is calculated by determining the number of positions for which the nucleotide or the amino-acid is identical between the two sequences, by dividing this number of identical positions by the total number of positions in the "comparison window" and by multiplying the result obtained by 100, to obtain the percentage of identity between these two sequences.

[0078] The step (b) of expanding the antigen-specific Tr1 cell population according to the present invention using feeder cells, offers the following advantages:

- The feeder cell expansion system is capable to maintain exponential growth of the antigen-specific Tr1 cell population for at least two or three months *in vitro*,
- The feeder cells lack MHC class I and II molecules to avoid allogeneic response,
- The feeder cells are mycoplasma-free,
- The feeder cells are capable to grow well using serum free medium,
- The feeder cells do not require to be irradiated,
- The feeder cells do not allow the expansion of mammal viruses, and
- The expanded antigen-specific Tr1 cell population is very well characterized for injection purposes.

[0079] Another object of the invention is an *in vitro* method for the obtention of a food- or auto-antigen specific Tr1 cell population from a human leukocyte population or a human peripheral blood mononuclear cell (PBMC) population, said method consisting of:

1. 1) stimulating the human PBMC or leukocyte population with the food- or auto-antigen,
2. 2) recovering the food- or auto-antigen specific Tr1 cell population from the stimulated cell population, and
3. 3) expanding said antigen-specific Tr1 cell population by contacting said antigen-specific Tr1 cell population with CD3+CD28 beads in the presence of IL-2 and IL-4.

In one embodiment, the food- or auto-antigen specific Tr1 cell population is obtained from a PBMC population.

In one embodiment, the PBMC or leukocyte population is re-stimulated at least once with the same antigen after step (1), in the presence of interleukin-2 (IL-2) and at least one interleukin selected from the group consisting of interleukin-4 (IL-4) and interleukin-13 (IL-13).

In one embodiment, the food- or auto-antigen is a recombinant or a synthesized antigen.

In one embodiment, the food-antigen is selected from the group comprising ovalbumin, casein, soya protein, fragments, variants and mixtures thereof. In one embodiment, the food-antigen is selected from the group comprising chicken egg ovalbumin of sequence SEQ ID N°23, bovin alpha S1-casein of sequence SEQ ID N°24, bovin beta-casein of sequence SEQ ID N°25, and sequences having at least 70 % of identity with one of the sequences SEQ ID N°23, SEQ ID N°24 and SEQ ID N°25.

In another embodiment, the auto-antigen is selected from the group comprising insulin, myelin basic protein, fragments, variants and mixtures thereof.

In one embodiment, the PBMC population stimulated at step (1) contains from $0.01 \cdot 10^6$ to $100 \cdot 10^6$ cells/mL, preferably from 10^6 to $2 \cdot 10^6$ cells/mL.

In one embodiment, the food- or auto-antigen used for stimulation of the PBMC population at step (1) is in a soluble form from 0.1 µg/mL to 5 mg/mL, preferably from 1 to 2000 µg/mL.

[0080] The present invention is further described in the following figures and examples. These figures and examples are provided for purposes of illustration only, and are not intended to be limiting the scope of the appended claims. The various scenarios are relevant for many practical situations, and are intended to be merely exemplary to those skilled in the art. Thus, the invention should be construed to encompass any and all variations that become evident as a result of the teaching provided herein.

LEGENDS OF THE FIGURES

Figure 1: CD4⁺CD18^{bright}CD49b⁺ Tr1 cells proliferate in response to food antigens and not to recall antigens.

[0081] A) Purified CD4⁺ T cells (grey bars), CD4⁺CD18^{bright}CD49b⁺ Tr1 cells (white bars) and CD4⁺CD45RO⁺CD49b⁻ memory T cells were stimulated with tetanus toxoid (10 µg/mL), PPD (20 µg/mL) or anti-CD3+antiCD28 mAb (10 µg/mL) in the presence of autologous purified monocytes. Proliferation was analysed by thymidine incorporation at day 5. B) the same population as in A were stimulated with ovalbumin (OVA, 20 µg/mL), Casein (20 µg/mL) or a mixture of soya proteins (Soya) at 50 µg/mL). Results represent the mean proliferative response of 10 different patients.

Figure 2: CD4⁺CD18^{bright}CD49b⁺ T cells proliferate to food antigen and not to vaccine antigen.

[0082] CD4⁺ T cells or purified CD4⁺CD45RO⁺CD49b⁻ or CD4⁺CD18⁺CD49b⁺ were labelled with CFSE and stimulated with the different antigen as indicated, either vaccine antigen (PPD, purified protein derivative: tuberculin, TT: tetanus toxoid) or food antigen (OVA : ovalbumin, Casein or Soya protein). After 8 days, cells were analyzed by cytofluorometry, and the percentage of divided cells was analyzed by the decreased expression of CFSE. The percentage of CFSE^{low} cells is indicated in each quadrant.

Figure 3: Food antigen-specific CD4⁺ proliferative T cells have a Tr1 cytokine profile phenotype.

[0083] CD4⁺ T cells were labelled with CFSE and stimulated with the indicated vaccine (PPD, TT) or food (OVA, Soya, Casein) antigen. CFSE^{low} CD4⁺ T cells were purified and restimulated with anti-CD3 and anti-CD28 mAb, and after 48hr the supernatants were analyzed by ELISA to measure the amounts of the indicated cytokines. Food antigen specific proliferative CD4⁺ T cells displayed a Tr1 phenotype with IL-10^{high} IL-4⁻ IFN-γ^{+/-}, IL-5^{+/-} IL-2⁻ secretion level, whereas recall antigen-specific T cells displayed a Th1 phenotype with high IFN-γ secretion.

Figure 4: CD4⁺CD18^{bright}CD49b⁺ T cells proliferate to auto-antigen and auto-antigen-specific cells displayed a Tr1 cytokine phenotype.

[0084] CD4⁺ T cells or purified CD4⁺CD45RO⁺CD49b⁻ or CD4⁺CD18⁺CD49b⁺ were labelled with CFSE and stimulated with an auto-antigen (MBP : myelin basic protein) or insulin as indicated. After 8 days, cells were analyzed by cytofluorometry, and the percentage of divided cells was analyzed by the decreased expression of CFSE. The percentage of CFSE^{low} cells is indicated in each quadrant. CFSE^{low} T cells were purified and restimulated with anti-CD3 and anti-CD28 mAb, and after 48hr the supernatants were analyzed by ELISA to measure the amount of the indicated cytokines. Auto-antigen specific proliferative CD4⁺ T cells displayed a Tr1 phenotype with IL-10^{high} IL-4⁻ IFN-γ^{+/-}, IL-5^{+/-}, IL-2⁻ secretion levels.

Figure 5: Tr1 cells can be observed in patients suffering from autoimmune or allergic diseases to the tested antigen

[0085] CD4⁺ T cells or purified CD4⁺CD45RO⁺CD49b⁻ or CD4⁺CD18⁺CD49b⁺ were isolated from a patient suffering from multiple sclerosis (MS) or allergy to casein as indicated, labelled with CFSE and stimulated with autoantigen (MBP : myelin basic protein), or casein or purified protein derivative from mycobacterium tuberculosis (PPD) as a positive control as indicated. After 8 days, cells were analyzed by cytofluorometry, and the percentage of divided cells was analyzed by the decreased expression of CFSE. The percentage of CFSE^{low} cells is indicated in each quadrant. CFSE^{low} T cells were purified and restimulated with anti-CD3 and anti-CD28 mAb, and after 48hr the supernatants were analyzed by ELISA to measure the amounts of the indicated cytokines.

Figure 6: Food antigen-specific Tr1 cells did not proliferate in response to IL-2 alone but proliferated vigorously in response to IL-2 and IL-4.

[0086] CD4⁺ T cells were labelled with CFSE, stimulated with the indicated antigens and purified as in Figure 3. The purified cells were then expanded in the presence of IL-2 alone (1 µg/mL) or IL-2 and IL-4 (1 µg/mL and 500 ng/mL respectively). The number of cells under the different conditions was then measured and plotted against the number of days after initiation. Recall antigen T cells proliferated in response to IL-2 and the combination of IL-2 and IL-4 whereas food-antigen-specific Tr1 cells proliferated only against the combination of IL-2 and IL-4 cytokines.

Figure 7: IL-2 and IL-4 expanded food antigen-specific Tr1 cells maintain their cytokine profile after expansion

[0087] The different antigen-specific T cell population as obtained in Figure 5 were stimulated with CD3 and CD28 mAb and their cytokine profile was determined by ELISA in supernatants collected 48 hr after stimulation. PPD- and TT-specific T cells maintained their Th1 cytokine profile after expansion with IL-2 alone, whereas IL-4 addition induced the secretion of IL-4 in these cells as expected. In contrast, food-antigens-specific Tr1 cells maintained their cytokine profile even after expansion in the presence of IL-2 and IL-4.

Figure 8: Analysis of human protein expression on S2 cell line.

[0088] Two-color flow-cytometry analysis of OKT3 heavy and light chains and CD80 and CD58 expression in parental (S2) or cell factory (CF) cells.

Figure 9: Cartoon of engineered CF interacting with a CD4 +Tr1 cell

[0089] S2 cells were transfected with a membrane bound anti-CD3 mAb to engage the TCR/CD3 complex, CD80 and CD58 to add some costimulatory signals through interaction with CD28 and CD2 molecules respectively, and IL-2 and IL-4 to induce cell growth.

Figure 10: Proliferation of T cells induced by CF cell line.

[0090] Proliferation of polyclonal PBLs, CD4 +T cells Tr1 cells lines (L1 and L2) or Tr1 clones (C1 and C2) stimulated with the cell factory was measured by [³H]thymidine incorporation between days 3 and 4 culture. T cells were stimulated with CF cells as indicated, in the absence of exogenous cytokines. At 72 h, the cells were pulsed with [³H]thymidine and incubated for an additional 18 h before harvesting. Counts per minute values are shown as mean s.e.m. from triplicate cultures.

Figure 11: Long-term growth of primary polyclonal human Tr1 cells stimulated with cell factory.

[0091] Tr1 cells were stimulated with CD3/28 beads plus exogenous IL-2 and IL-4, CF⁺ cells expressing OKT3, CD80 and CD58 but not IL-2 and IL-4 in the presence of exogenous IL-2 and IL-4, or with the complete cell factory system without any exogenous addition. T cells were stimulated with CF cells on days 0, 10, and 20 of culture.

Figure 12: Purity of T cells after co-culture with CF cell line.

[0092] The purity of T cells and after stimulation with CF cell line was assessed by staining for CD3, CD4 expression during the first seven days of culture. Gating on cell size/debris was not used in this experiment so as to represent all cells in the culture. Viable cells are indicated by gating on propidium iodide to exclude dead cells. Results are representative of >10 different experiments, each with a different donor.

Figure 13: Fate of CF cell line after co-culture with T cells

[0093] The fate of CF stimulator cells were assessed by staining for CD4 and OKT3H expression during the first seven days of culture. Gating on cell size/debris was not used in this experiment so as to represent all cells in the culture. Viable cells are indicated by gating on propidium iodide to exclude dead cells. Results are representative of > 10 different experiments, each with a different donor.

Figure 14: Schematic representation of the experimental protocol used.

Figure 15: Isolation of OVA-specific Tr1 clones.

[0094] PBL stained with CFSE were stimulated with OVA, and stained with CD4 CD49b and CD18. CD4+CD49b+CD18^{bright} cells were gated and CFSE cells were sorted. Sorted cells were cloned to generate clone 1 and 2, the bulk population was stimulated with OVA and stained with IL-10 and IFN- γ revealing a Tr1 phenotype.

Figure 16: Analysis of long term proliferation of Tr1 clones

[0095] Two clones were then stimulated with the irradiated cell factory. The total cell numbers are depicted in a semi-log plot of cell number vs. days in culture.

Figure 17: Cytokine profile of OVA-specific T clones land 2 after expansion on the cell factory for 70 days.

[0096] Cytokine were measured in the supernatants of the clones stimulated with OVA and autologous irradiated monocytes. Antigen-specific suppression was also examined by a transwell assay. Autologous PBLs were stimulated with anti-CD3 mAb in the bottom well, no cells, control CD4 T cells and the two clones were added in the top basket and stimulated with anti-CD3 and autologous irradiated monocytes for CD4 cells or OVA and irradiated autologous monocytes for the two Tr1 clones. The entire protocol is representative of ten experiments, each from different donors.

EXAMPLES

EXAMPLE 1: *IN VITRO* OBTENTION OF A FOOD- OR AUTO-ANTIGEN SPECIFIC TR1 CELL POPULATION FROM A PBMC POPULATION BY STIMULATION WITH THE FOOD- OR AUTO-ANTIGEN

1.1 Material and methods

Cell purification and flow cytometry

[0097] Human peripheral blood mononuclear cells (PBMC) were recovered from Buffy coats of healthy donors after cenTr1fugation on ficoll gradient. CD4⁺ T lymphocytes were purified from PBMC after depletion of CD11b⁺ (OKM1-95), CD20⁺ (1F5C9), and CD8⁺ (G42-8) cells by negative selection using Goat antimouse-coated Dynabeads (Dyna, Oslo, Norway). Monocytes were purified by adherence after culture of PBMC 1 hour at 37°C in RPMI supplemented with 20% FCS. More than 90% of the recovered adherent cells were CD14⁺ monocytes. CD4⁺ T lymphocytes were separated in CD49b⁺CD18^{bright} or CD49b⁺CD45RO⁺ T cells after staining the cells with fluorescent antibodies and sorted on a FACS vantage SE, Beckton Dickinson, Le pont de Claix, France). The following antibodies were used for flow cytometry: FITC, APC or PC5 -labeled mouse anti-human CD4 (RPA-T4), PC5 -labeled mouse anti-human CD3 (UCHT1), PE - labeled mouse anti-human CD49b (12FI-H6), FITC -labeled mouse anti-human CD14 (M5-E2), PE or PC5 -labeled mouse anti-human CD18 (6.7), PE -labeled mouse anti-human CD25 (M-A251), PE -labeled mouse anti-human HLA-DR (G46-6), PE -labeled mouse anti-human CD69 (FN50), FITC

anti-human CD45RO (UCHL-1). All antibodies were purchased from BD-Pharmingen (Le Pont de Claix, France).

Cell culture

[0098] For detection of CD4⁺ antigen-specific T lymphocytes, PBMCs (10 million cells/mL) were stained with either 0,2 µM CFSE or 2.5 µM PKH26 (Molecular Probes, Leiden, Rolland) during 5 minutes at 37°C in PBS 1X. After two washes in PBS 1X, cell populations were incubated at 2 million/mL in RPMI supplemented with 5% human serum AB in the presence or absence of 200 µg/mL of chicken Ovalbumin, 200 µg/mL of bovine Caseine, 200 µg/mL of human Insulin (Sigma, L'Isle d'Abeau, France), 50 µg/mL of Tetanus toxoid (Lederie, Pearl River, New York) and 2µg/mL of Purified Protein Derivative (PPD) from mycobacterium Tuberculosis (Staten serum Institute, Danmark) or 50 µg/mL of MBP (Sigma, L'Isle d'Abeau, France). After 9 days of culture, cells were stained with PC5- labeled mouse anti-human CD4 and analyzed by flow cytometry. CD49b⁺CD18^{bright} or CD49b⁺CD45RO⁺ T cells were also sorted, stained with 0,2 µM CFSE or 2.5 µM PKH26 and cultured at 2 million/mL in the presence of 4.10⁵ autologous monocytes and in the presence of antigens.

Sorting and expansion of antigen specific cells

[0099] After 10 days of culture, CD4+CFSE10 or CD4+PICE26 10 antigen-specific T cells were sorted on a FACS vantage SE (Beckton Dickinson) and expanded with autologous irradiated PBMCs in the presence of antigens, in X-vivo 15 medium (Biowhittaker, Emerainville, france) supplemented with 10 ng/mL of IL4 and 5 ng/mL of IL2.

Cytokine detection

[0100] Cytokine production was detected by ELISA that were performed on supernatants of human cells populations (2 million/mL) cultured 48 hours in RPMI supplemented with 10% FCS (Life Technologies, Cergy Pontoise, France) and stimulated with 10 µg/mL of coated anti-CD3 (UCHT1) and 1 µg/mL of soluble anti-CD28 (CD28.2). Antibodies used were anti-IL10 (JES3-9D7), anti-IL4 (8D4), anti-IL2 (17H12), anti-ILS (39D10) and anti-IFN γ (A35) capture antibodies and NIP- labeled anti -IL10 (JES3-12D8), anti-IL4 (MP4-25D2), anti-IL2 (B33-2), anti-IL5 (5A10) and anti-IFN γ (B27) detection antibodies followed by Peroxydase-labeled anti-NIP antibody and ABTS addition. IL10, IL4 and IFN γ were from R&D systems (Minneapolis, MN), IL2 was from Chiron corp (Emmeryville,CA). All antibodies were from BD pharmingen.

Proliferation measurement

[0101] To assess proliferation, T cell populations (1 million cells/mL) were stimulated in vitro with autologous irradiated PBMCs and specific antigens in RPMI supplemented with 10% FCS at 37°C in the presence of indicated cytokines. T cell proliferation was evaluated by the numeration of live cells.

Methods to isolate antigen-specific Tr1 cells

[0102] The inventors designed methods to isolate populations and clones of antigen- specific Tr1 cells.

The first method relies on CFSE or any similar dye (PHK), incorporation. The cells are labelled with CFSE and stimulation with food antigen (range from 0.1 µg/mL to 5 mg/mL), after 9 to 10 days, the cells are sorted by cytofluorometry and maintained with CD3+CD28 beads and IL-2+IL-4. In order to remove any other cells that could have not significantly proliferated under these culture conditions, the cells could also be cloned at one cell per well and the different clones analyzed for specificity and cytokine secretion.

The second method relies on cell surface expression of activation or proliferation markers. The PBMC are stimulated with food or autoantigens and the antigen-stimulated cells are purified by antibodies directed against anti-CD69, anti-CD25 or any activation or proliferation markers. Purified cells are then maintained with CD3+CD28 stimuli and IL-2+ IL-4. Alternatively cells can be maintained with feeder cells and CD3/CD28 stimuli, in the presence of IL-2 and IL-4. Purified cells could also be cloned at one cell per well by FACS sorting or limiting dilution.

The third method is based on the enrichment of the proliferative population after stimulation with food or autoantigens. PBMC are

stimulated with ovalbumin (or any other food or autoantigen) and after one the week the cells were restimulated with the same antigen in the presence of IL-2 and IL-4. That combination was optimal but any combination or time period could be used. The enriched population was then cloned by limiting dilution (but any other cloning technique could be used). The clones were then multiplied by stimulation with feeder cells anti-CD3, CD28 and IL-2 and IL-4. The proliferating clones were then analyzed for specificity and cytokine secretion by using ovalbumin presented by autologous irradiated PBMCs.

1.2 Results

CD4⁺CD3⁺CD49b⁺CD18^{bright} Tr1 cells proliferate in response to food antigens and not to vaccine antigens.

[0103] When the inventors purified CD4⁺CD3⁺CD49b⁺CD18^{bright} Tr1 cells, they observed that these cells did not proliferate in response to recall antigens like tetanus toxoid of PPD, in contrast to the reciprocal population (Fig 1A). They also tested the ability of CD4⁺CD3⁺CD49b⁺CD18^{bright} Tr1 cells to proliferate to food antigens. As previously reported, only very minimal proliferative response over background was observed when the total CD3⁺CD4⁺ T cell population was stimulated with food antigens (Ovalbumin, casein, soya protein or bovine immunoglobulins). However they observed a vigorous proliferative response in the purified CD4⁺CD3⁺CD49b⁺CD18^{bright} Tr1 cells populations, whereas no proliferation was observed in the reciprocal memory population (Fig 1B).

[0104] They therefore used a more sensitive technique with CFSE incorporation, and observed that Tr1 cells did not proliferate to recall antigens but displayed a significant proliferative response to food antigens like ovalbumin, casein or soya proteins. In contrast the reciprocal population of CD4⁺ T cells did not show any proliferative response to food antigens but proliferated vigorously to recall antigens (TT and PPD) (Fig 2).

Food antigen-specific CD4⁺CD3⁺CD49b⁺CD18^{bright} T cells have a Tr1 cytokine profile.

[0105] Using the CFSE incorporation technique (Figure 3), the inventors isolated by FACS the CFSE^{low} proliferating cells and analyzed their cytokine profile by a polyclonal stimulus (anti-CD3+CD28 mAbs). These experiments showed that OVA, Casein, and soya-specific cells have a Tr1 cytokine profile secreting high levels of IL-10, some IFN- γ , some IL-5 and no IL-2 and IL-4 as previously described (Groux et al. Nature 1997). In contrast, the TT- or PPD-specific cells displayed a Th1 phenotype secreting mainly IFN- γ as expected.

Tr1 cells are also specific for autoantigens

[0106] Using the CFSE technique the inventors also analyzed the proliferative response of the different CD4⁺ T cell populations to autoantigens like MBP (myelin basic protein) or insulin. Similarly to food antigens, minimal to no proliferative response was observed in the bulk CD4⁺ population (as reported) or in the CD49b⁺ memory (CD45RO⁺) population. Surprisingly, vigorous proliferation response was observed when purified CD4⁺CD3⁺CD49b⁺CD18^{bright} Tr1 cells were stimulated with insulin or MBP. Moreover, these insulin- or MBP-specific cells displayed a Tr1 cytokine profile with high IL-10 secretion (Fig 4).

Tr1 cells can be isolated in patients suffering from autoimmunity or allergy to the tested antigen

[0107] As food antigen and autoantigen have been implicated in allergic or autoimmune diseases respectively, the inventors analyzed the presence of proliferative T cells in the purified CD4⁺CD3⁺CD49b⁺CD18^{bright} T cell population of patients suffering from MS (with an autoimmune disease directed against myelin component like MBP) or patients with food allergy to casein. As shown in Figure 5 they observed that, as expected, MBP- or Casein-stimulation induces cell proliferation into the purified CD4⁺CD3⁺CD45RO⁺CD49b⁻ in a patient suffering from multiple sclerosis or Casein-allergy respectively. Restimulation of the proliferative cells showed that as expected these cells displayed a Th1 cytokine profile in the case of the cells from a patient suffering from MS stimulated with MBP, and a Th2 cytokine profile in response to Casein in the case of the allergic patient.

However, unexpectedly they also observe a proliferation in the CD4⁺CD3⁺CD49b⁺CD18^{bright} Tr1 cell population as in normal control showing that food or auto-antigen specific Tr1 cells could also be observed in patients suffering of autoimmunity or allergy to the tested antigen (Fig 5).

The combination of IL-2 and IL-4 is required to maintain the Ag-specific Tr1 cell proliferation.

[0108] Although Tr1 cells (CD4⁺CD3⁺CD49b⁺CD18^{bright} cells) proliferated in response to food or autoantigens, that proliferation could not be maintained by the addition of IL-2 alone (Fig 6) in contrast to the proliferation of TT- or PPD- specific T cells (Fig 6). Surprisingly, the inventors found that the combined addition of IL-2 and IL-4 was able to maintain the proliferative response of food antigens or autoantigen specific Tr1 cells (Fig 7).

EXAMPLE 2: EXPANSION OF THE OBTAINED ANTIGEN-SPECIFIC TRI CELL POPULATION USING FEEDER CELLS

2.1 Experimental protocol

Labelled antibodies

For bead sorting:

[0109] Beads used:

- " MagCelect Ferrofluid, Streptavidin " (*R&D*)
- " Sheep anti-Rat beads " (*Dako*)

For CD80: biotinylated mouse-anti-human CD80 (B7-1), clone L307.4 (*BD Biosciences Pharmingen*)

For OKT3 : purified Rat-anti-mouse Ig Kappa light chain, clone 187.1 (*BD Biosciences Pharmingen*)

For FACS sorting and usual control markers

[0110]

For CD80: mouse-anti-human CD80-PE (phycoerythrine) or FITC (fluorescein isothiocyanate), clone L307.4 (*BD Biosciences Pharmingen*)

For CD58: mouse-anti-human CD58-PE or PECy5 (phycoerythrin-cyanin 5) (LFA-3) Clone 1C3 (*BD Biosciences Pharmingen*)

For OKT3 :

- *Heavy chain*: biotinylated anti-mouse IgG2a, clone R19-15 + Streptavidine-FITC or Streptavidine-PE or Streptavidine-PECy5 (*BD Biosciences Pharmingen*)
- *Light chain*: purified Rat-anti-mouse Ig Kappa light chain, clone 187.1 (*BD Biosciences Pharmingen*) + Rabbit-anti-Rat-FITC (*Dako*)

Amplifications primers

[0111]

OKT3-LFWD:

5'- ATGCGGATCC ATGGATTTTCAAGTGCAG- 3' (SEQ ID N° 9)

OKT3-LREV:

5'- ATGCGAATTCCTAACACTCATTCTGTTG- 3' (SEQ ID N° 10)

primer OKT3H1 variable heavy chain (571pb):

HSPAT1 FWD:

5'- ATG CCC GCG GGG TAC CCA CTG AAA ACT CTG ACT CAA C - 3' (SEQ ID N° 11)

OKT3 H2/3 REV:

5'-ACTGGACAGGGATCCAGAGTTC-3' (SEQIDN° 12)

primer OKT3H2 heavy chain CH1-CH3 (850pb).

OKT3 H3/5 FWD :

5'- GAA CTC TGG ATC CCT GTC CAG TG- 3' (SEQ ID N° 13)

OKT3 H3/3 REV:

5'- ATG CGA ATT CTT TAC CCG GAG TCC GGG AGA AGC TC- 3' (SEQ ID N° 14)

primer pdgfr platelet-derived growth factor receptor, beta (151pb)

PDGFR 5 FWD :

5'- ATG CGA ATT CGC TGT GGG CCA GGA CAC GCA G- 3' (SEQ ID N° 15)

PDGFR3 REV:

5'- ATG CGG GCC CAA GCT TCT AAC GTG GCT TCT TCT GCC AAA G-3' (SEQ ID N° 16)

IL-2 FWD:

5'- ATGCGGATCCATGTACAGGATGCAACTCCT - 3' (SEQ ID N° 17)

IL-2REV:

5'- ATGCGAATTCCTCAAGTCAGTGTGAGATGA- 3' (SEQ ID N° 18)

LFA3 FWD:

5'- ATGCTGGATCCATGGTTGCTGGGAGCGACGC- 3' (SEQ ID N° 19)

LFA3 REY:

5'- ATGCTAAGCTTTCAA TTGGAGTTGGTTCTGT - 3' (SEQ ID N° 20)

IL-4 FWD:

5'- ATGCGGATCCATGGGTCTCACCTCCCAACT- 3' (SEQ ID N° 21)

IL-4REV:

5'- ATGCAAGCTTTCAGCTCGAACACTTTGAAT- 3' (SEQ ID No 22)

Cloning and construction of cell factory

[0112] Human CD80, IL-2, IL-4 and CD58 were cloned from peripheral blood T lymphocytes (PBLs) obtained from a healthy

donor into the pAC vector (Invitrogen) using an insect actin promoter (Chung and Keller, *Mol Cell Biol.* 1990 Dec;10(12):6172-80; Chung and Keller, *Mol Cell Biol.* 1990 Jan;10(1):206-16) and transfected by electroporation (electroporator Biorad, US) into S2 cells from the S2 cell line deposited on March 25, 2005 at the CNCM under the number I-3407. Similarly, the heavy and light chains of OKT3 (Kung et al, *Science.* 1979 Oct 19;206(4416):347) were cloned from the OKT3 hybridoma cells (ATCC CRL 8001; Manassas, Virginia, USA) into the pAC vector and transfected into S2 cells before FACS. To obtain membrane bound anti-CD3 mAb the 3' end of the heavy chain was removed and replaced by the transmembrane part of the platelet derived growth factor (PDGF) gene CF' cells, that is to say cells expressing hCD80, hCD58 and anti-CD3 monoclonal antibody (mAb) and CF, that is to say cells expressing hCD80, hCD58, hIL-2 hIL-4 and anti-CD3 monoclonal antibody (mAb) were isolated by fluorescence-activated cell sorting FACS using the antibodies as described above. No selection marker was used and the stably transfected cells were selected by FACS staining. The sorted cells were cloned and for each round of transfection and selection, the most efficient clone for the stimulation of Tr1 cells was selected.

CD4+T-lymphocyte preparation and S2 cell culture

[0113] Fresh peripheral blood lymphocytes were obtained by Ficoll hypaque centrifugation, and CD4 +T cells were purified by negative selection using anti-CD8 antibody (Becton Dickinson). All cultures were maintained in X-vivo without serum addition (BioWhittaker, Walkersville, MD). Human IL-2 (Chiron Therapeutics, Emeryville, CA) was added at 20 IU/mL where indicated, hIL-4 was used at 1 µg/mL (for comparing the biological advantage obtained when feeder cells express the interleukins with the results obtained when recombinant interleukins are added in the culture medium). S2 cells were maintained in SFM medium without serum (Gibco).

Flow cytometry and FACS sorting

[0114] Cells were stained with antibodies at 4°C, and analyzed on a FACSCalibur (BD BioSciences, Mountain View, CA) or sorted with the FACStar system.

2.2 Results

Construction of aAPCs

[0115] To test the hypothesis that Tr1 cells have distinct co-stimulation requirements for long-term growth, the inventors designed a cell-based system that could be genetically manipulated to express different co-stimulatory molecules and cytokines in addition to CD3/CD28 classical stimuli. They chose S2 cells because they do not express human HLA proteins that would promote allogeneic responses, and they could not be contaminated by human viruses (Fig. 8). Also, the eventual introduction of irradiated feeder cells into the clinical setting can be avoided because these cells which grow at 27°C are easily killed at 37°C and are propagated in serum-free medium. The inventors transfected and then cloned S2 cells expressing the human CD80, the human CD58 and the two chains of an anti-hCD3 mAb to permit the stimulation of human Tr1 cells (CF') (Fig. 8). Similarly, they generated the CF line (Figs. 8, 9) by transfecting CF' cells with human IL-4 and IL-2 cDNA. Cultures were initiated by adding CF cells to fresh human CD4+ T cells prepared by negative selection (see Experimental Protocol).

CF cell line efficiently activate human polyclonal CD4+ T cells and Tr1 cells

[0116] The cell factory was tested for its ability to stimulate the initial activation and proliferation of primary CD4+ T cells as well as Tr1 cell lines or Tr1 cell clones. The different purified T cells were stimulated with the cell factory at an 1/1 ratio. The inventors found that the initial rate of growth of the T cells stimulated with the cell factory was equivalent, as judged by [3H] thymidine incorporation (Fig.10) with a slight enhancement of Tr1 cells proliferative response over other CD4+ T cells. The inventors confirmed this observation by labeling fresh T cells with carboxyfluorescein diacetate succinimidyl ester (CFSE) and tracking cell division during the first five days of culture (data not shown). They also found that the cell- based system was more efficient than CD3/28 beads for the induction of proliferation and cell division of CD4+ T cells (data not shown). No proliferation was seen when the cell factory, or CD4+ T cells incubated separately (Fig. 10 and data not shown). Thus, the requirements for the initial rounds of CD4+ T-cell proliferation was even more satisfactory with the cell factory as compared to CD3/CD28 stimulation provided in the

context of polystyrene beads.

CF cell line permit long-term expansion of human Tr1 cells

[0117] Next, the inventors determined whether the cell factory was sufficient to maintain long-term propagation of Tr1 cells (Fig. 11). Tr1 cells were stimulated with CF that secrete hIL-2 and IL-4, with CF' that do not secrete cytokine but with addition of exogenous cytokines and, CD3/28 beads with exogenous cytokines. CD3/28 bead-stimulated cells failed to proliferate after the second stimulation, in agreement with previous studies. Similarly, Tr1 cells stimulated with CF' in the context of IL-2 and IL-4 added exogenously entered into a plateau phase of the growth curve within two to three weeks of culture, and no additional net growth of cells occurred after re-stimulation. In contrast, when Tr1 cell cultures were stimulated with the cell factory, they remained in exponential growth even after a third stimulation. This augmentation of long-term proliferation was reproducible, as the average increase in the total number of T cells was 810-fold higher in cultures stimulated with the cell factory than in cultures stimulated with CD3/28 beads in six independent experiments.

[0118] Phenotypic analysis of cultures showed a progressive enrichment for CD3+CD4+ T cells after stimulation with the cell factory (Fig. 12). The S2 cells rapidly disappeared from the cell culture, as evidenced by an inability to detect the cells expressing the anti-CD3 mAb by flow cytometry after seven days (Fig. 13); this finding was confirmed in large-scale experiments and also by RT-PCR for drosophila genes (data not shown). Thus, the mixed T-cell and cell factory culture yields a population of pure T cells within one week.

Efficient propagation of antigen-specific Tr1 cells by the cell factory

[0119] Immunotherapy with Tr1 cells will likely require cells with antigen-specific regulatory functions. To determine whether the cell factory could be used to expand antigen-specific Tr1, the inventors used them to culture OVA-specific Tr1 clones for 10 weeks (Fig. 14). An example of two different clones is shown by the experiment has been performed with hundreds of different autoantigens- or food antigen-specific T cell clones. PBLs from a normal individual were labeled with CFSE to follow cell division and the cells were stimulated with ovalbumin (20 µg/mL) for 7 days. Cells were then stained with CD4, CD18 and CD49b to select for Tr1 cells overexpressing these markers and OVA-specific cells were sorted according to the decrease in CFSE labelling due to antigen-specific cell division (Fig. 15). To control their phenotype a bulk sorted population was stimulated with OVA and cytokine production was analyzed by intracytoplasmic staining which revealed a typical Tr1 population (Fig. 15). After cloning, the cells were stimulated with the cell factory (Fig. 16). All cells were re-stimulated with the cell factory at 10-days intervals. No specific OVA stimulation was provided during culture. Exponential growth curves of both clones were obtained for several months. The one antigen-specific Tr1 cell yielded 1.5×10^9 cells after one and an half month of culture, a number of cells sufficient for immunotherapy. The substantial proliferative capacity of the Tr1 cells that remains after 30 days of culture suggests that these Tr1 could have substantial long-term engraftment potential after adoptive transfer.

[0120] To determine if antigen specificity of the expanded populations was maintained during culture, cells were stimulated with OVA (Fig. 17). After one month and an half of culture, the cells were stimulated with OVA and autologous APCs and cytokine secretion was analyzed. A typical Tr1 profile was observed for the two different clones analyzed.

[0121] To examine the effector function of the cultured Tr1 cells, the antigen-specific suppressive function was tested in a typical transwell assay (Fig. 17 and data not shown). Both clones displayed a typical Tr1 suppressive effect on bystander cells. Suppression was due to IL-10 and TGF- β 3 secretion as shown by the use of blocking antibodies (not shown). No suppression was obtained in the absence of OVA stimulation (data not shown). Similar results were obtained with different donors and different Tr1 clones (data not shown).

SEQUENCE LISTING

[0122]

<110> Institut National de la Santé et de la Recherche Médicale (INSERM)
GROUX, Hervé
COTTREZ, Françoise

<120> Obtention of food- or auto-antigen specific Tr1 cells from a leukocyte or PBMC population

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<151> 2005-07-01

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gtaactttcc atgtaccaag caatgtgcoo ttaaaagagg tcctatggaa aaaacaaaag      180
gataaagtgt cagaactgga aaattctgaa ttcagagctt tctcatcttt taaaaatagg      240
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gatgagtatg aaatggaaatc gccaaatatt actgatacca tgaagtcttt tctttatgtg      360
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caatgcatga taccagagca ttacaacagc catcgaggac ttataatgta ctcatgggat      480
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cttccacaaa aaatacagtg tactcttagc aatccattat ttaatacaac atcatcaatc      600
attttgaaa cctgtatccc aagcagcggg .cattcaagac acagatatgc acttataccc      660
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<223> Nucleic sequence encoding IL4

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aagaacacaa ctgagaagga aaccttctgc agggctgcga ctgtgctccg gcagttctac      240
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ctctgcaatg gcagcatggt atggagcacc aacctgacag ctggcatgta ctgtgcagcc      240
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agcggattct gcccgacaaa ggtctcagct gggcagtttt ccagcttgca tgtccgagac      360
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Lys Glu Leu Lys Val His His Ala Asn Glu Asn Ile Phe Tyr Cys Pro
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Ile Ala Ile Met Ser Ala Leu Ala Met Val Tyr Leu Gly Ala Lys Asp
 35           40           45

Ser Thr Arg Thr Gln Ile Asn Lys Val Val Arg Phe Asp Lys Leu Pro
 50           55           60

Gly Phe Gly Asp Ser Ile Glu Ala Gln Cys Gly Thr Ser Val Asn Val
 65           70           75           80

His Ser Ser Leu Arg Asp Ile Leu Asn Gln Ile Thr Lys Pro Asn Asp
 85           90           95

Val Tyr Ser Phe Ser Leu Ala Ser Arg Leu Tyr Ala Glu Glu Arg Tyr
 100          105          110

Pro Ile Leu Pro Glu Tyr Leu Gln Cys Val Lys Glu Leu Tyr Arg Gly
 115          120          125

Gly Leu Glu Pro Ile Asn Phe Gln Thr Ala Ala Asp Gln Ala Arg Glu
 130          135          140

Leu Ile Asn Ser Trp Val Glu Ser Gln Thr Asn Gly Ile Ile Arg Asn
 145          150          155          160

Val Leu Gln Pro Ser Ser Val Asp Ser Gln Thr Ala Met Val Leu Val
 165          170          175

Asn Ala Ile Val Phe Lys Gly Leu Trp Glu Lys Ala Phe Lys Asp Glu
 180          185          190

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Asp Thr Gln Ala Met Pro Phe Arg Val Thr Glu Gln Glu Ser Lys Pro
 195 200 205

Val Gln Met Met Tyr Gln Ile Gly Leu Phe Arg Val Ala Ser Met Ala
 210 215 220

Ser Glu Lys Met Lys Ile Leu Glu Leu Pro Phe Ala Ser Gly Thr Met
 225 230 235 240

Ser Met Leu Val Leu Leu Pro Asp Glu Val Ser Gly Leu Glu Gln Leu
 245 250 255

Glu Ser Ile Ile Asn Phe Glu Lys Leu Thr Glu Trp Thr Ser Ser Asn
 260 265 270

Val Met Glu Glu Arg Lys Ile Lys Val Tyr Leu Pro Arg Met Lys Met
 275 280 285

Glu Glu Lys Tyr Asn Leu Thr Ser Val Leu Met Ala Met Gly Ile Thr
 290 295 300

Asp Val Phe Ser Ser Ser Ala Asn Leu Ser Gly Ile Ser Ser Ala Glu
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Ser Leu Lys Ile Ser Gln Ala Val His Ala Ala His Ala Glu Ile Asn
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 340 345 350

Ala Ser Val Ser Glu Glu Phe Arg Ala Asp His Pro Phe Leu Phe Cys
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Glu Asn Leu Leu Arg Phe Phe Val Ala Pro Phe Pro Glu Val Phe Gly
 35 40 45

Lys Glu Lys Val Asn Glu Leu Ser Lys Asp Ile Gly Ser Glu Ser Thr

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Patentkrav

1. Fremgangsmåde in vitro til opnåelse af en fødevare- eller autoantigenspecifik Tr1-cellepopulation fra en human leukocytpopulation eller en human perifer blodmononukleær cellepopulation (PBMC), hvilken fremgangsmåde omfatter:
5
1) stimulering af den humane PBMC- eller leukocytpopulation med fødevare- eller autoantigenet,
2) genvinding af den fødevare- eller autoantigenspecifikke Tr1-cellepopulation fra den stimulerede cellepopulation,
10 forudsat at fremgangsmåden ikke omfatter stimulering af humane perifere blodlymfocytter med ovalbumin.
2. Fremgangsmåde ifølge krav 1, hvor den fødevare- eller autoantigenspecifikke Tr1-cellepopulation opnås fra en PBMC-population.
15
3. Fremgangsmåde ifølge krav 1 eller 2, hvor PBMC- eller leukocytpopulationen stimuleres mindst én gang til med det samme antigen efter trin (1) i nærvær af interleukin-2 (IL-2) og mindst én interleukin, der er udvalgt fra gruppen bestående af interleukin-4 (IL-4) og interleukin-13 (IL-13).
20
4. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 3, hvor fødevare- eller autoantigenet er et rekombinant eller et syntetiseret antigen.
5. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 4, hvor fødevare-antigenet er udvalgt fra gruppen, der omfatter casein, sojaprotein, fragmenter, varianter og blandinger deraf.
25
6. Fremgangsmåde ifølge krav 5, hvor fødevareantigenet er udvalgt fra gruppen, der omfatter bovin alpha S1-casein med sekvens SEQ ID nr. 24, bovin beta-casein med sekvens SEQ ID nr. 25, og sekvenser, der er mindst 70 % identisk med én af sekvenserne SEQ ID nr. 24 og SEQ ID nr. 25.
30
7. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 4, hvor autoantigenet er udvalgt fra gruppen, der omfatter insulin, myelin basisk protein, fragmenter, varianter og

blandinger deraf.

8. Fremgangsmåde ifølge et hvilket som helst af kravene 2 til 7, hvor PBMC-populationen, der stimuleres i trin (1), indeholder fra $0,01 \cdot 10^6$ til $100 \cdot 10^6$ celler/mL, fortrinsvis fra 10^6 til $2 \cdot 10^6$ celler/mL.
5
9. Fremgangsmåde ifølge krav 8, hvor fødevare- eller autoantigenet, der anvendes til stimulering af PBMC-populationen i trin (1), er i en opløselig form fra $0,1 \mu\text{g/mL}$ til 5 mg/mL , fortrinsvis fra 1 til $2000 \mu\text{g/mL}$.
10
10. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 9, hvor PBMC- eller leukocytpopulationen er inkuberet, inden stimulation i trin (1), med en fluorescerende celledelingsmarkør, der gør det muligt at bestemme, ved cytofluorometri, når den fluorescerende intensitet af den stimulerede cellepopulation er mindst to gange lavere end den fluorescerende intensitet af PBMC- eller leukocytpopulationen, at celledelingen har fundet sted i den stimulerede cellepopulation, og at den stimulerede cellepopulation, der er genvundet i trin (2), omfatter den antigen-specifikke Tr1-cellepopulation.
15
11. Fremgangsmåde ifølge krav 10, hvor den fluorescerende celledelingsmarkør er carboxyfluorescein-diacetat-succinimidylester- (CFSE) markøren, oregon green 488 carboxylsyre-diacetat- (Carboxy-DFFDA SE) markøren eller PKH26-markøren.
20
12. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 11, hvor den antigen-specifikke Tr1-cellepopulation genvindes i trin (2) ved cytofluorometri ved anvendelse af fluorescerende mærkede antistoffer, der er rettet mod proteiner, der er til stede på overfladen af cellerne af den antigen-specifikke Tr1-cellepopulation.
25
13. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 12, hvor den antigen-specifikke Tr1-cellepopulation genvindes i trin (2) ved en kloningsteknik, såsom fortrinsvis ved begrænsende fortynding.
30
14. Fremgangsmåde *in vitro* til opnåelse af en fødevare- eller autoantigenspecifik Tr1-cellepopulation fra en human leukocytpopulation eller en human perifer blodmononukleær cellepopulation (PBMC), hvilken fremgangsmåde omfatter:

- a) genvinding af den fødevare- eller autoantigenspecifikke Tr1-cellepopulation fra trin 2 ifølge et hvilket som helst af kravene 1 til 13 og
- b) udvidelse af den antigen-specifikke Tr1-cellepopulation ved etablering af kontakt mellem den antigen-specifikke Tr1-cellepopulation og CD3+CD28-kugler i nærvær af IL-2 og IL-4.
- 5
15. Fremgangsmåde *in vitro* til opnåelse af en fødevare- eller autoantigenspecifik Tr1-cellepopulation fra en human leukocytpopulation eller en human perifer blodmononukleær cellepopulation (PBMC), hvilken fremgangsmåde omfatter:
- 10 a) genvinding af den fødevare- eller autoantigenspecifikke Tr1-cellepopulation fra trin 2 ifølge et hvilket som helst af kravene 1 til 13 og
- b) udvidelse af den antigen-specifikke Tr1-cellepopulation i et dyrkningsmedium Mp, hvor trinnet med udvidelse omfatter:
- i. dyrkning i en temperatur T1 i et dyrkningsmedium Mf, af næringsceller, der er i stand til at udtrykke en gruppe af rekombinante faktorer, som interagerer med følgende celleoverfladeproteiner fra den antigen-specifikke Tr1-cellepopulation, der skal udvides:
- 15 - CD3/TCR-proteinkompleks,
- CD28-protein,
- CD2-protein,
20 - interleukin-2 (IL-2)-receptor, og
- interleukin-4 (IL-4)-receptor,
hvor sådan T1 muliggør proliferering af næringscellerne,
- ii. etablering af kontakt mellem næringscellerne, der er opnået i trin (a) og frigjort eller ikke frigjort af deres dyrkningsmedium Mf, og den antigen-specifikke Tr1-cellepopulation, der er indeholdt i dyrkningsmediet Mp, hvor dyrkningsmediet Mp ikke fra starten indeholder gruppen af faktorer for at opnå en blanding indeholdende den antigen-specifikke Tr1-cellepopulation, næringsceller og dyrkningsmediet Mp,
- 25 iii. dyrkning af blandingen, der er opnået i trin (b) og som indeholder faktorerne fra gruppen, der udtrykkes af næringscellerne i dyrkningsmediet Mp, hvor trinnet (c) med dyrkning udføres ved en temperatur T2, der er mindst ca. 35 °C, således at:
- 30 - den antigen-specifikke Tr1-cellepopulation prolifererer, og
- næringscellerne ikke prolifererer, og hvor den antigen-specifikke Tr1-cellepopulation udvides,
- iv. genvinding af den således udvidede antigen-specifikke Tr1-cellepopulation.

16. Fremgangsmåde ifølge krav 15, hvor næringscellerne dør under trin (iii).
- 5 17. Fremgangsmåde ifølge krav 16, hvor i trin (iv) cellemembranfragmenterne fra næringscellerne, der forekommer ved cellernes død, elimineres.
18. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 17, hvor gruppen af faktorer omfatter faktorer, der forankres til næringscellernes cellemembran, og faktorer, der sekreteres af næringscellerne.
- 10 19. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 18, hvor næringscellerne er rekombinante celler og indeholder heterologe nukleinsyrer, der koder for gruppens faktorer.
- 15 20. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 19, hvor næringscellerne ikke har noget indre større histokompatibilitetskompleks- (MHC) molekyle af klasse I og/eller klasse II på deres overflade.
- 20 21. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 20, hvor i trin (ii) næringscellerne er frigjort for deres dyrkningsmedium Mf.
22. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 21, hvor næringscellerne er insektnæringsceller med T1, der er under T2.
- 25 23. Fremgangsmåde ifølge krav 22, hvor insektnæringscellerne er fra S2 drosophila-cellelinjen, som blev indleveret den 25. marts, 2005 til National Collection of Microorganisms Cultures (CNCM) under nummer 1-3407.
- 30 24. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 23, hvor dyrkningsmediet Mp er et serumfrit dyrkningsmedium.
25. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 24, hvor dyrkningsmediet Mf er et serumfrit dyrkningsmedium.

26. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 25, hvor gruppen af rekombinante faktorer omfatter:
- det modificerede anti-CD3-antistof, hvor modifikationen af anti-CD3-antistoffet består af erstatningen af det anti-CD3-intracytoplasmiske domæne af anti-CD3-tungkæden med et transmembrandomæne, hvilket modificerede anti-CD3-antistof er forankret til næringscellernes cellemembran og tilbøjeligt til at interagere med CD3/TCR-proteinkomplekset af T-cellerne, eller en variant deraf,
 - CD80- eller CD86-proteinet, fortrinsvis CD80-proteinet, der er forankret til næringscellernes cellemembran og tilbøjeligt til at interagere med CD28-proteinet af T-cellerne, eller en variant deraf, og
 - CD58-proteinet, der er forankret til næringscellernes cellemembran og tilbøjeligt til at interagere med CD2-proteinet af Tr1-cellerne, eller en variant deraf,
 - IL-2, der er sekretet af næringscellerne og tilbøjeligt til at interagere med IL-2-receptoren af Tr1-cellerne, eller en variant deraf, og
 - et interleukin, der er udvalgt fra gruppen, der omfatter IL-4 og interleukin 13 (IL-13), fortrinsvis IL-4, hvilket interleukin sekretes af næringscellerne og er tilbøjeligt til at interagere med IL-4-receptoren af Tr1-cellerne, eller en variant deraf.
27. Fremgangsmåde ifølge krav 26, hvor transmembrandomænet, der erstatter det intracytoplasmiske domæne af anti-CD3-antistoftungkæden, er transmembrandomænet af PDGF-vækstfaktor- (platelet derived growth factor) receptoren.
28. Fremgangsmåde ifølge krav 26 eller 27, hvor gruppens faktorer er af human oprindelse.
29. Fremgangsmåde ifølge krav 28, hvor
- letkæden af det modificerede anti-CD3-antistof kodes af den heterologe nukleinsyre med sekvens SEQ ID nr. 1, eller en hvilken som helst nukleinsyre, der er mindst 70 % identisk med SEQ ID nr. 1, og hvor tungkæden fra det modificerede anti-CD3-antistof kodes af den heterologe nukleinsyre med sekvens SEQ ID nr. 2, eller en hvilken som helst nukleinsyre, der er mindst 70 % identisk med SEQ ID nr. 2; og/eller
 - Fremgangsmåde ifølge krav 30 eller 31, hvor CD80-proteinet kodes af den heterologe nukleinsyre med sekvens SEQ ID nr. 3, eller en hvilken som helst nukleinsyre, der er mindst 70 % identisk med SEQ ID nr. 3, og/eller

- Fremgangsmåde ifølge krav 30 eller 31, hvor CD86-proteinet kodes af den heterologe nukleinsyre med sekvens SEQ ID nr. 4, eller en hvilken som helst nukleinsyre, der er mindst 70 % identisk med SEQ ID nr. 4, og/eller
 - Fremgangsmåde ifølge et hvilket som helst af kravene 30 til 33, hvor CD58-proteinet kodes af den heterologe nukleinsyre med sekvens SEQ ID nr. 6, eller en hvilken som helst nukleinsyre, der er mindst 70 % identisk med SEQ ID nr. 6, og/eller
 - Fremgangsmåde ifølge et hvilket som helst af kravene 30 til 34, hvor IL-2 kodes af den heterologe nukleinsyre med sekvens SEQ ID nr. 5, eller en hvilken som helst nukleinsyre, der er mindst 70 % identisk med SEQ ID nr. 5, og/eller
 - Fremgangsmåde ifølge et hvilket som helst af kravene 30 til 35, hvor IL-4 kodes af den heterologe nukleinsyre med sekvens SEQ ID nr. 7, eller en hvilken som helst nukleinsyre, der er mindst 70 % identisk med SEQ ID nr. 7, og/eller
 - Fremgangsmåde ifølge et hvilket som helst af kravene 30 til 36, hvor IL-13 kodes af den heterologe nukleinsyre med sekvens SEQ ID nr. 8, eller en hvilken som helst nukleinsyre, der er mindst 70 % identisk med SEQ ID nr. 8.
30. Fremgangsmåde ifølge et hvilket som helst af kravene 15 til 29, hvor den således udvidede antigen-specifikke Tr1-cellepopulation genvindes i trin (iv) efter dyrkning af den antigen-specifikke Tr1-cellepopulation i trin (iii) i mindst 12 timer, fortrinsvis 24 timer.
31. Fremgangsmåde *in vitro* til opnåelse af en fødevare- eller autoantigenspecifik Tr1-cellepopulation fra en human leukocytpopulation eller en human perifer blodmononukleær cellepopulation (PBMC), hvilken fremgangsmåde består af:
- 1) stimulering af den humane PBMC- eller leukocytpopulation med fødevare- eller autoantigenet,
 - 2) genvinding af den fødevare- eller autoantigenspecifikke Tr1-cellepopulation fra den stimulerede cellepopulation, og
 - 3) udvidelse af den antigen-specifikke Tr1-cellepopulation ved etablering af kontakt mellem den antigen-specifikke Tr1-cellepopulation og CD3+CD28-kugler i nærvær af IL-2 og IL-4.
32. Fremgangsmåde ifølge krav 31, hvor den fødevare- eller autoantigenspecifikke Tr1-

cellepopulation opnås fra en PBMC-population.

- 5 33. Fremgangsmåde ifølge krav 31 eller 32, hvor PBMC- eller leukocytpopulationen stimuleres mindst én gang til med det samme antigen efter trin (1), i nærvær af interleukin-2 (IL-2) og mindst ét interleukin, der er udvalgt fra gruppen bestående af interleukin-4 (IL-4) og interleukin-13 (IL-13).
- 10 34. Fremgangsmåde ifølge et hvilket som helst af kravene 31 til 33, hvor fødevare- eller autoantigenet er et rekombinant eller et syntetiseret antigen.
- 15 35. Fremgangsmåde ifølge et hvilket som helst af kravene 31 til 34, hvor fødevareantigenet er udvalgt fra gruppen, der omfatter ovalbumin, casein, sojaprotein, fragmenter, varianter og blandinger deraf.
- 20 36. Fremgangsmåde ifølge krav 35, hvor fødevareantigenet er udvalgt fra gruppen, der omfatter kyllingeægovalbumin med sekvens SEQ ID nr. 23, bovin alpha S1-casein med sekvens SEQ ID nr. 24, bovin beta-casein med sekvens SEQ ID nr. 25, og sekvenser, der er mindst 70 % identiske med én af sekvenserne SEQ ID nr. 23, SEQ ID nr. 24 og SEQ ID nr. 25.
- 25 37. Fremgangsmåde ifølge et hvilket som helst af kravene 31 til 36, hvor autoantigenet er udvalgt fra gruppen, der omfatter insulin, myelin basisk protein, fragmenter, varianter og blandinger deraf.
- 30 38. Fremgangsmåde ifølge et hvilket som helst af kravene 31 til 37, hvor PBMC-populationen, der er stimuleret i trin (1), indeholder fra $0,01 \cdot 10^6$ til $100 \cdot 10^6$ celler/mL, fortrinsvis fra 10^6 til $2 \cdot 10^6$ celler/mL.
39. Fremgangsmåde ifølge krav 38, hvor fødevare- eller autoantigenet, der anvendes til stimulation af PBMC-populationen i trin (1), er i en opløselig form fra $0,1 \mu\text{g/mL}$ til 5 mg/mL , fortrinsvis fra 1 til $2000 \mu\text{g/mL}$.

DRAWINGS

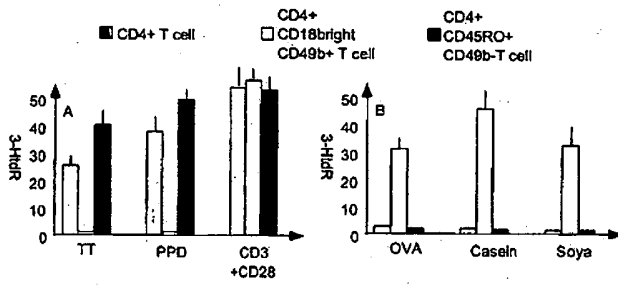


Figure 1

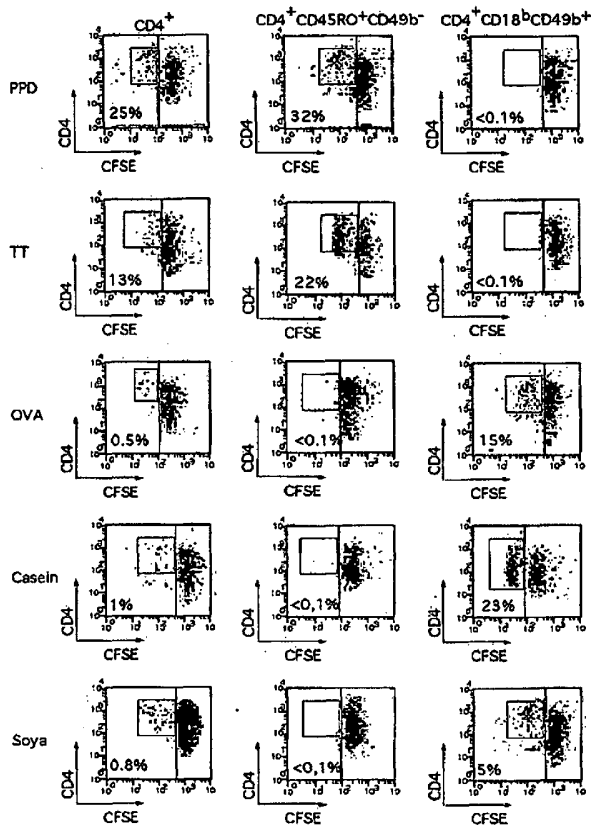


Figure 2

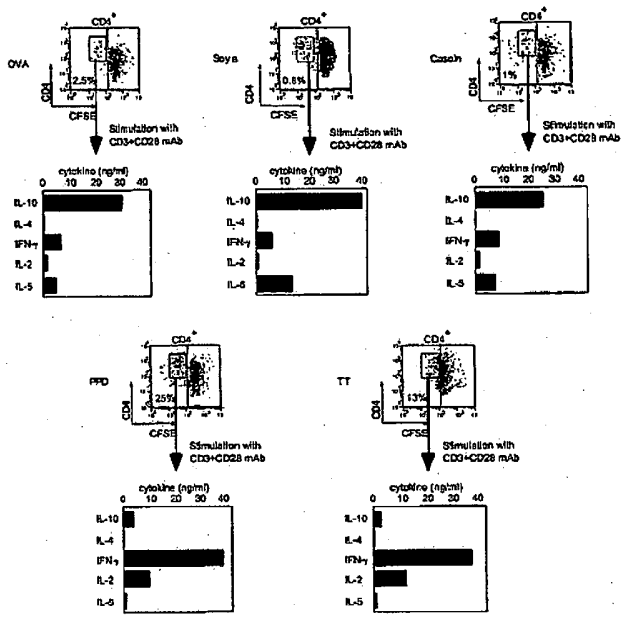


Figure 3

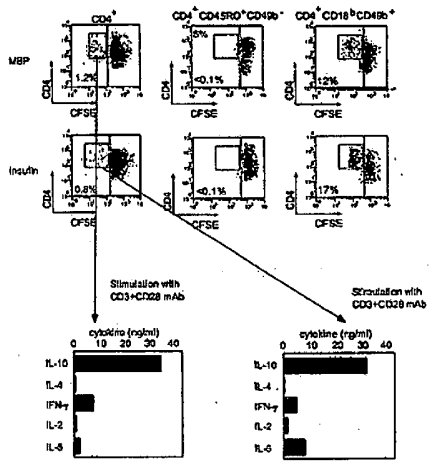


Figure 4

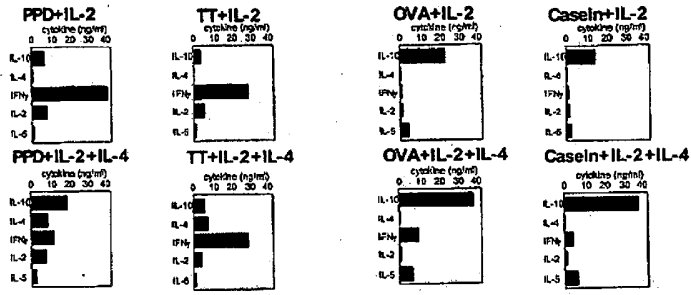


Figure 7

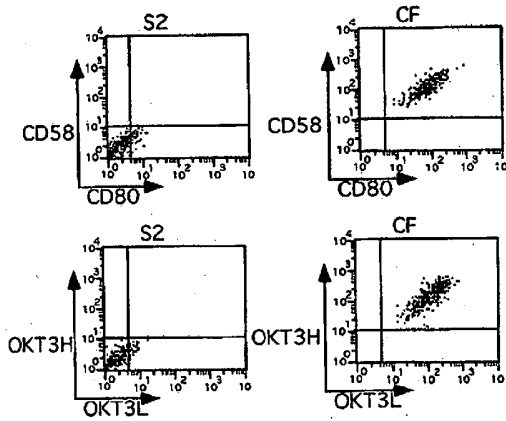


Figure 8

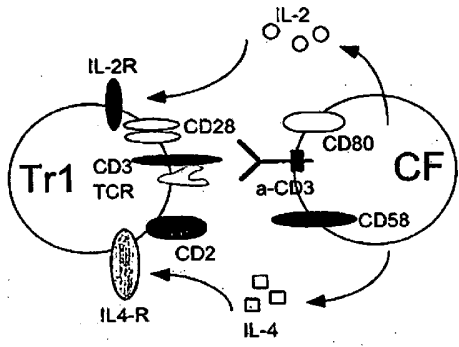


Figure 9

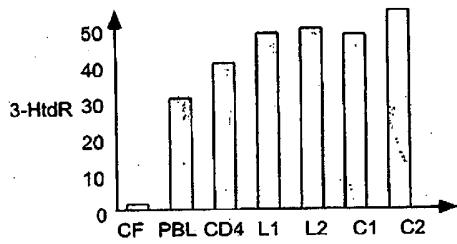


Figure 10

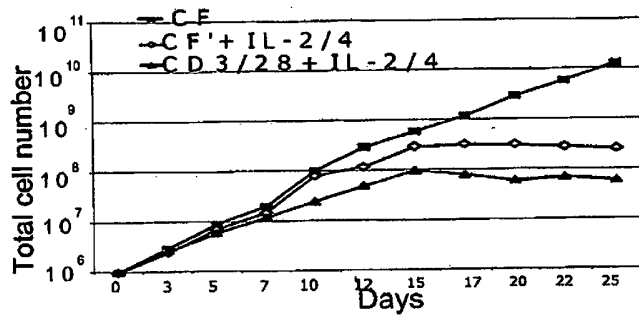


Figure 11

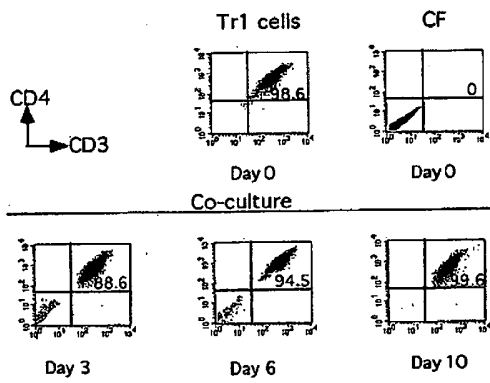


Figure 12

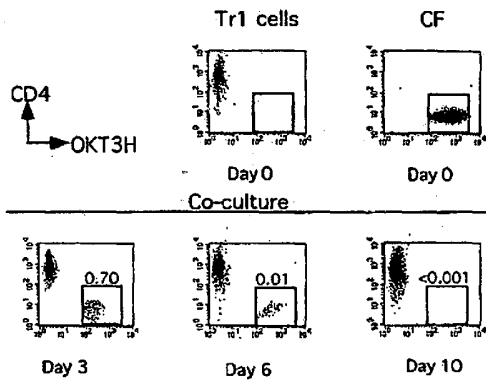


Figure 13

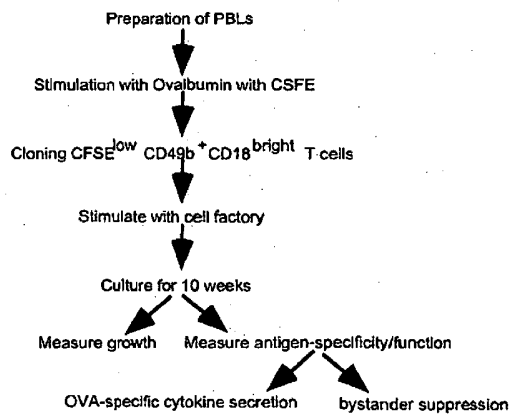


Figure 14

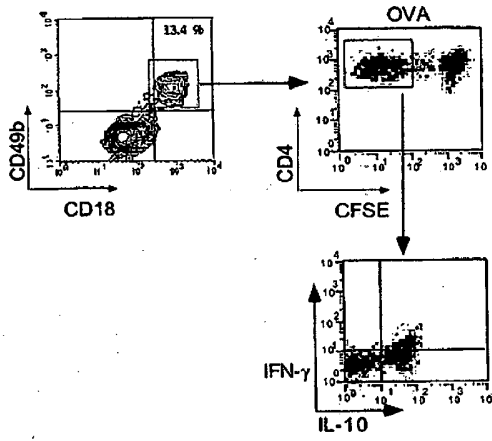


Figure 15

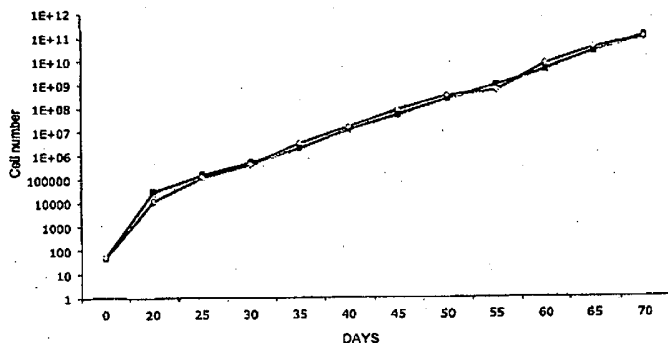


Figure 16

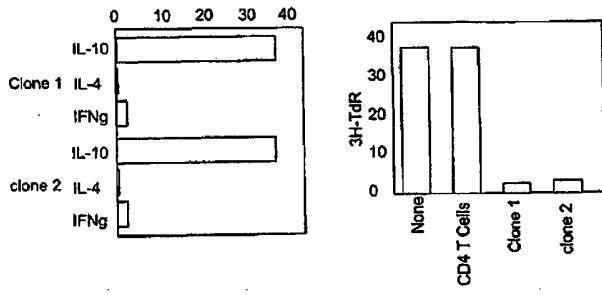


Figure 17