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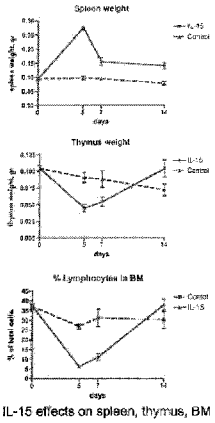
Figure 2



IL-15 effects on spleen, thymus, BM

(57) Abstract: The present invention provides method for promoting the maturation and export of T cells from thymic tissue by contacting the thymic tissue with supraphysiological levels of interleukin (IL)-15. The present invention also provides methods for preventing, alleviating, reducing, and/or inhibiting lymphopenia or peripheral depletion of lymphocytes in a patient in need thereof by administering to the patient IL-15.

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USE OF IL-15 TO INCREASE THYMIC OUTPUT AND TO TREAT LYMPHOPENIA

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of U.S. provisional application no. 61/234,152, filed August 14, 2009; and U.S. provisional application no. 61/234,155, filed August 14, 2009. Each application is herein incorporated by reference.

FIELD OF THE INVENTION

[0002] The present invention provides compositions and methods for promoting the maturation and export of T cells from the thymus, *e.g.*, to peripheral lymphoid and non-lymphoid tissues by contacting the thymus tissue, *in vitro* or *in vivo*, with interleukin (IL)-15.

[0003] The invention additionally provides methods for preventing, alleviating, reducing, and/or inhibiting lymphopenia or depletion of lymphocytes in peripheral tissues in a patient in need thereof by administering IL-15 to the patient.

BACKGROUND OF THE INVENTION

[0004] Two common gamma-chain cytokines, IL-2 and IL-7 are currently approved or considered for both AIDS and cancer immunotherapy. *See*, Sportes, *et al.*, (2008) *J Exp Med* 205:1701-1714; Levy, Y. (2009) *J Clin Invest.* 119(4):997-100785; and Rosenberg, *et al.*, (2006) *J Immunother* 29:313-319. No clinical experience exists with the gamma-chain cytokine IL-15. *See*, Cheever, (2008) *Immunological Reviews* 222:357-368.

[0005] IL-15 is a non-redundant cytokine important for the development, survival, and proliferation of natural killer (NK) and CD8+ T-cells. It shares with IL-2 the same IL-2 beta gamma receptor and has many similar effects on lymphocytes, but unlike IL-2 is not produced by lymphocytes but by a plethora of other cells including, importantly, antigen presenting cells and macrophages, and stroma cells in several tissues. The biological effects of IL-2 and IL-15 at the level of the organism are dramatically different, as shown by work in knockout mice: lack of IL-15 causes immune system defects, whereas lack of IL-2 causes immune activation and severe autoimmunity. *See*, Waldmann, (2006) *Nat Rev Immunol* 6:595-601; and Ma, *et al.*, (2006) *Annu Rev Immunol* 24:657-679. Both cytokines are under tight and complex regulation at all steps of expression and secretion. The biological

differences of IL-2 and IL-15 are determined by their different production sites, their strength of association with membrane receptor proteins termed IL-2 Receptor alpha and IL-15 Receptor alpha (IL-15Rα), respectively, and the regulation of these extra receptor molecules. IL-15 has been also reported to have a unique mechanism of action *in vivo* among the common gamma chain cytokines: IL-15 functions in a complex with IL-15Rα and depends on the co-expression by the same cells of IL-15Rα. *See*, Burkett, *et al.*, (2004) *J Exp Med* 200:825-834; Burkett, *et al.*, (2003) *Proc Natl Acad Sci USA* 100:4724-4729; Dubois, *et al.*, (2002) *Immunity* 17:537-547; Sandau, *et al*, (2004) *J Immunol* 173:6537-6541; Schluns, *et al.*, (2004) *Blood* 103:988-994; Rubinstein, *et al.*, (2006) *Proc Natl Acad Sci USA* 103:9166-9171; Bergamaschi, *et al.*, (2008) *J Biol Chem* 283:4189-4199. IL-15 has non-redundant roles in the development and function of NK and intestinal intraepithelial lymphocytes (IELs). *See*, Cooper, *et al.*, (2001) *Blood* 97:3146-3151. It stimulates cytolytic activity, cytokine secretion, proliferation and survival of NK cells. *See*, Fehniger, *et al.*, (1999) *J Immunol* 162:4511-4520; Ross, *et al.*, (1997) *Blood* 89:910-918; and Carson, *et al.*, (1994) *J Exp Med* 180:1395-1403. IL-15 has a proliferative and survival effect on CD8+ memory T-cells and naive CD8+ T-cells. *See*, Tan, *et al.*, (2002) *J Exp Med* 195:1523-1532; Zhang, *et al.*, (1998) *Immunity* 8:591-599; Berard, *et al.*, (2003) *J Immunol* 170:5018-5026; and Alves, *et al.*, (2003) *Blood* 102:2541-2546.

[0006] Several studies have evaluated the effects of IL-15 administration in vivo. CD8+ memory T-cell proliferation increased after a single dose of IL-15 in normal mice. *See*, Zhang, *et al.*, (1998) *Immunity* 8:591-599. Administration of IL-15 to mice enhanced the antitumor activity after syngeneic bone marrow transplantation (BMT) and antigen-specific primary CD8+ T-cell responses following vaccination with peptide-pulsed dendritic cells. *See*, Rubinstein, *et al.*, (2002) *J Immunol* 169:4928-4935; Katsanis, *et al.*, (1996) *Transplantation* 62:872-875. IL-15 also enhanced immune reconstitution after allogeneic bone marrow transplantation. *See*, Alpdogan, *et al.*, (2005) *Blood* 105:865-873; and Evans, *et al.*, (1997) *Cell Immunol* 179:66-73. The ability of IL-15 to promote growth, survival and activation of key lymphocyte populations make it also an attractive candidate for supporting growth in vitro and in vivo of cells for adoptive cell therapy. *See*, Rosenberg, *et al.*, (2008) *Nat Rev Cancer* 8:299-308; and Berger, *et al.*, (2008) *J Clin Invest* 118:294-305.

[0007] We have demonstrated that efficient production of IL-15 requires the expression of IL-15 and IL-15 Receptor alpha (IL-15Rα) in the same cell. *See*, Bergamaschi, *et al.*, (2008) *J Biol Chem* 283:4189-4199. Co-production leads to intracellular association of IL-15 and IL-15Rα in the endoplasmic reticulum, stabilization of both molecules and efficient transport

to the cell surface (Figure 1). We showed that an additional critical step is the rapid cleavage and release of the IL-15/IL-15Rα complex from the cell surface, both in vitro and in vivo, resulting in a soluble, systemically active form of IL-15/IL-15Rα, in addition to the bioactive complex on the cell surface. *See*, Dubois, *et al.*, (2002) *Immunity* 17:537-547; Bergamaschi, *et al.*, (2008) *J Biol Chem* 283:4189-4199; and Budagian, *et al.*, (2004) *J Biol Chem* 279:40368-40375. Our experiments using IL-15 complexed to a deletion mutant of IL-15Rα containing only the soluble Receptor alpha extracellular fragment demonstrated that this complex is bioactive *in vivo* in the absence of any membrane-bound form.

[0008] Therefore, we proposed that IL-15Rα is part of a heterodimeric IL-15 cytokine, rather than functioning as a cytokine receptor. These results have been supported by other investigators, and provide the basis for a better understanding of IL-15 biology. *See*, Duitman, *et al.*, (2008) *Mol Cell Biol* 28:4851-4861; Mortier, *et al.*, (2008) *J Exp Med* 205:1213-1225. The results also provide the molecular basis to explain some intriguing observations, including the requirement of production of IL-15 and IL-15Rα from the same cells for appropriate function *in vivo*. *See*, Sandau, *et al.*, (2004) *J Immunol* 173:6537-6541; and Koka, *et al.*, (2003) *J Exp Med* 197:977-984. Such results are fully explained by our finding that stabilization during co-expression in the same cell is required for physiological levels of IL-15 production. It has also been reported that the cells that physiologically express IL-15 also express IL-15Rα, consistent with IL-15 production as a heterodimer in the body. *See*, Dubois, *et al.*, (2002) *Immunity* 17:537-547; Giri, *et al.*, (1995) *J Leukoc Biol* 57:763-766; and Ruckert, *et al.*, (2003) *Eur J Immunol* 33:3493-3503. Interpretation of all data available to date suggests that the main bioactive form of IL-15 is in a complex with the Receptor alpha either on the surface of the cells or in a soluble circulating form. It remains to be determined whether single-chain IL-15 is produced in the body in physiologically relevant levels and what is its exact function.

[0009] It has been previously reported that IL-15 secretion is inefficient. *See*, Bamford, *et al.*, (1998) *J Immunol* 160:4418-4426; Gaggero, *et al.*, (1999) *Eur J Immunol* 29:1265-1274; Kurys, *et al.*, (2000) *J Biol Chem* 275:30653-30659; Onu, *et al.*, (1997) *J Immunol* 158:255-262; and Tagaya, *et al.*, (1997) *Proc Natl Acad Sci USA* 94:14444-14449. We took a systematic approach to develop IL-15 expression vectors producing high levels of bioactive cytokine based on the observation that multiple regulatory steps during gene expression create bottlenecks of IL-15 production. *See*, Jalah, *et al.*, (2007) *DNA Cell Biol* 26:827-840; and Kutzler, *et al.*, (2005) *J Immunol* 175:112-123. We showed that combination of two approaches, namely mRNA optimization (RNA/codon optimization) of the IL-15 coding

sequences and substitution of the signal peptide with other efficient secretory signals resulted in synergistically improved expression and secretion of bioactive IL-15. *See*, Jalah, *et al.*, (2007) *DNA Cell Biol* 26:827-840. Taking advantage of the stabilization of IL-15 by co-expression with IL-15Rα described above, we produced equally optimized vectors for IL-15Rα and combination vectors expressing both molecules, as well as combinations producing only the soluble heterodimeric cytokine. The final improvement in expression of secreted IL-15 was more than 1,000 fold compared to wt IL-15 cDNA, as determined by in vitro and in vivo experiments. We have produced similar vectors for mouse, macaque and human IL-15/IL-15Rα.

[0010] Two forms of interleukin-15 (IL-15) are known, containing a long signal peptide (LSP) or a short signal peptide (SSP), respectively. The two forms are produced by alternatively spliced mRNAs and differ only in the length of their signal peptides, the 48 aa long signal peptide or the 21 aa short signal peptide (120, 121, 125-127). *See*, Onu, *et al.*, (1997) *J Immunol* 158:255-262; Tagaya, *et al.*, (1997) *Proc Natl Acad Sci USA* 94:14444-14449; Meazza, *et al.*, (1997) *Eur J Immunol* 27:1049-1054; Meazza, *et al.*, (1996) *Oncogene* 12:2187-2192; and Nishimura, *et al.*, (1998) *J Immunol* 160:936-942. Whereas LSP IL-15 is secreted, SSP IL-15 remains exclusively intracellular and its function is not known. It has been proposed that SSP IL-15 may have a regulatory function since it was detected both in the cytoplasm and the nucleus of DNA-transfected cells. The SSP signal affects both stability and localization of IL-15, since lower levels of the SSP isoform were detected when the two isoforms were expressed from similar vectors. *See*, *See*, Onu, *et al.*, (1997) *J Immunol* 158:255-262; Tagaya, *et al.*, (1997) *Proc Natl Acad Sci USA* 94:14444-14449; and Bergamaschi, *et al.*, (2009) *J Immunol*, 5:3064-72.

[0011] In Bergamaschi, we showed that, similar to LSP IL-15, SSP IL-15 is stabilized and secreted efficiently upon coexpression of IL-15Rα in the same cell. *See*, Bergamaschi, *et al.*, (2009) *J Immunol*, *supra*. Co-expression of SSP IL-15 and IL-15Rα in mice showed increased plasma levels of bioactive SSP IL-15 and mobilization and expansion of NK and T cells. Therefore, SSP IL-15 is secreted and bioactive when produced as a heterodimer with IL-15Rα in the same cell. The apparent stability of this complex both *in vitro* and *in vivo* is lower compared to LSP IL-15/IL-15Rα complex, as revealed by direct comparisons. This results in lower production of secreted bioactive IL-15/IL-15Rα. Thus, alternative splicing may provide the cell with the ability to produce different levels of bioactive IL-15. Since both forms of IL-15 may be produced in the same cell by alternative splicing, an additional level of regulation is possible. We showed that when both LSP IL-15 and SSP IL-15 are

produced in the same cell they compete for the binding to IL-15Rα, resulting in lower levels of bioactive IL-15. Therefore, co-expressed SSP IL-15 acts as competitive inhibitor of LSP IL-15. This suggests that usage of alternative splicing is an additional level of control of IL-15 activity. Expression of both SSP and LSP forms of IL-15 appears to be conserved in many mammals, suggesting that SSP may be important for expressing a form of IL-15 with lower magnitude and duration of biological effects. The present invention is based, in part, on the discovery that SSP IL-15, which is produced in the thymus, is important for intra-thymic effects on lymphocyte differentiation and maturation.

BRIEF SUMMARY OF THE INVENTION

[0012] The present invention provides compositions and methods that promote the maturation of T cells in the thymus and the output or migration of mature and/or activated lymphocytes from a central lymphoid organ to peripheral tissues by administration of IL-15. The invention is based, in part, on the discovery that IL-15 promotes the migration of T cells out of the thymus and subsequently to peripheral lymphoid (*e.g.*, spleen and lymph node) and non-lymphoid tissues (*e.g.*, lung and liver). In some embodiments, the methods concurrently promote the maturation of lymphocytes in the bone marrow, *e.g.*, B cells and natural killer (NK) cells, and their migration to peripheral lymphoid and non-lymphoid tissues.

[0013] Accordingly, in one aspect, the invention provides methods of promoting T-cell maturation in thymic tissue comprising contacting the thymic tissue with IL-15.

[0014] The thymic tissue can be *in vivo* or *in vitro*.

[0015] In a related aspect, the invention provides methods of promoting the migration of lymphocytes from a central lymphoid tissue to one or more peripheral tissues in a subject in need thereof comprising administering to the subject IL-15.

[0016] With respect to the embodiments, in some embodiments, the lymphocytes are T cells and the central lymphoid tissue is thymus. In some embodiments, the lymphocytes are B cells and/or NK cells and the central lymphoid tissue is bone marrow.

[0017] In some embodiments, the lymphocytes migrating from the central lymphoid tissues are mature but not activated. In some embodiments, the lymphocytes migrating from the central lymphoid tissues are mature and activated. In some embodiments, the T cells migrating from the thymus are mature single positive (CD4+ or CD8+) T cells. The T cells induced to leave the thymus may be activated or not activated.

[0018] The invention additionally provides methods for preventing, treating, alleviating, reducing and/or inhibiting lymphopenia or depletion of lymphocytes in peripheral tissues by administration of IL-15. The present invention further provides methods for promoting the repopulation of peripheral tissues that have been depleted of lymphocytes and accelerating the recovery from lymphocyte depletion of peripheral tissues by the administration of IL-15.

[0019] Accordingly, in one aspect, the invention provides methods of preventing, reducing or inhibiting lymphopenia or depletion of lymphocytes in peripheral tissues in an individual in need thereof comprising systemically administering IL-15 to the individual.

[0020] In some embodiments, the lymphopenia or lymphocyte depletion of peripheral tissues is drug-induced. For example, the individual may be receiving anticancer drugs or antiviral drugs, or radiation therapy that induces lymphopenia or lymphocyte depletion of peripheral tissues.

[0021] In some embodiments, the IL-15 is co-administered with an agent that causes depletion of lymphocytes in peripheral tissues, *e.g.*, an anticancer or an antiviral agent. In some embodiments, the IL-15 is co-administered with radiation therapy.

[0022] In a related aspect, the invention provides methods of promoting or accelerating the repopulation of lymphocytes in peripheral tissues in an individual in need thereof comprising systemically administering IL-15 to the individual.

[0023] In some embodiments, the systemic administration of IL-15 prevents or reduces the depletion of or promotes or accelerates the repopulation of one or more of T cells, B cells or NK cells. In some embodiments, the systemic administration of IL-15 prevents or reduces the depletion of or promotes or accelerates the repopulation of one or more of CD4+ T cells or CD8+ T cells.

[0024] In some embodiments of the methods of the invention, the subject or patient is a mammal. In some embodiments, the subject or patient is a human.

[0025] When administered *in vivo* the IL-15 can be administered systemically, including without limitation, enterally (*i.e.*, orally) or parenterally, *e.g.*, intravenously, intramuscularly, subcutaneously, intradermally, intranasally, or inhalationally. In some embodiments, the IL-15 is administered locally, for example, intrathymically.

[0026] Systemic administration is at a dose that is sufficient to maintain IL-15 at supraphysiologic levels. For example, IL-15 DNA or protein can be administered at a dose sufficient to achieve plasma levels of IL-15 of about 1 to 1000 ng/ml, for example, plasma

levels of IL-15 of about 10 to 1000 ng/ml. The IL-15 and IL-15Rα can be delivered in equimolar amounts. Such a range of IL-15 plasma concentrations can be achieved, *e.g.*, after intramuscular electroporation of about 0.1 mg IL-15/IL-15Rα expressing DNA plasmid per kg body weight. Alternatively, an IL-15/IL-15Rα protein complex can be administered at a dose of about 0.01 to 0.5 mg/kg. IL-15/IL-15Rα polypeptides can be administered, *e.g.*, subcutaneously, intramuscularly, intraperitoneally or intravenously. *See*, *e.g.*, Rosati, *et al.*, *Vaccine* (2008) 26:5223-5229.

[0027] The IL-15 can be administered as a polypeptide or as a polynucleotide encoding IL-15. In some embodiments, the IL-15 is co-administered with IL-15Rα, *e.g.*, as a heterodimer. The co-administered IL-15Rα can be a polypeptide or a polynucleotide encoding IL-15Rα. The co-administered IL-15Rα can be in the same or different form as the IL-15. For example, both the IL-15 and the IL-15Rα can be administered as polypeptides or as one or more polynucleotides encoding IL-15 and/or IL15Rα. Alternatively, one of the IL-15 and the IL15Rα can be administered as a polypeptide and the other as a polynucleotide encoding either IL-15 or IL-15Rα. In some embodiments, the IL-15Rα is a soluble IL-15Rα. In some embodiments, the IL-15Rα may be administered in the form of an Fc fusion protein or a polynucleotide that encodes an Fc fusion protein.

[0028] In some embodiments, the IL-15 and the IL-15Rα are concurrently administered as one or more polynucleotides encoding IL-15 and/or IL-15Rα. The polynucleotide encoding IL-15 and the polynucleotide encoding IL-15Rα can be on the same or separate vectors, for example, single or multiple plasmid vectors. In some embodiments, the IL-15 and the IL-15Rα polynucleotides are concurrently expressed from a plasmid vector of SEQ ID NO:13, SEQ ID NO:14, SEQ ID NO:15, SEQ ID NO:16, or SEQ ID NO: 19.

[0029] In some embodiments, the polynucleotides encoding one or both of IL-15 and the IL-15Rα are wild-type coding sequences. In some embodiments, the polynucleotide encoding IL-15 shares at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or 100% sequence identity to SEQ ID NO:1. In some embodiments, the polynucleotide encoding IL-15Rα shares at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or 100% sequence identity to SEQ ID NO:5 or SEQ ID NO:7.

[0030] In some embodiments, the polynucleotides encoding one or both of IL-15 and the IL-15Rα are codon optimized for improved expression over the wild-type coding sequences. In some embodiments, the polynucleotide encoding IL-15 shares at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or 100% sequence identity to SEQ ID NO:3 or SEQ

ID NO:4. In some embodiments, the polynucleotide encoding IL-15Rα shares at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or 100% sequence identity to SEQ ID NO:9 or SEQ ID NO:11.

[0031] When expressed from a polynucleotide encoding IL-15, the coding sequence can have a native or a heterologous signal peptide. In some embodiments, the signal peptide is a native IL-15 signal peptide, for example, the native IL-15 long signal peptide or the native IL-15 short signal peptide. In some embodiments, the signal peptide is a heterologous signal peptide, for example, a signal peptide from granulocyte-macrophage colony stimulating factor (GM-CSF), tissue plasminogen activator (tPA), growth hormone, or an immunoglobulin.

[0032] In some embodiments, the peripheral tissue is a peripheral lymphoid tissue, including without limitation, spleen, lymph node, mucosal-associated lymphoid tissues (MALT), *e.g.*, tonsils and/or gut-associated lymphoid tissues (GALT), including Peyer's patches.

[0033] In some embodiments, the peripheral tissue is a peripheral non-lymphoid tissue, *e.g.*, lung, liver, kidney, heart, skin, *etc.*

[0034] Preferably, the IL-15 is administered without an antigen, *i.e.*, is not co-administered with an antigen.

[0035] In a related aspect, the invention provides a DNA vector encoding IL-15 and IL-15Rα for use in promoting lymphocyte mobilization from central lymphoid tissue and migration to peripheral tissues.

[0036] In another aspect, the invention provides IL-15/IL-15Rα for use in promoting lymphocyte mobilization from central lymphoid tissue and migration to peripheral tissues.

[0037] In a related aspect, the invention provides a DNA vector encoding IL-15 and IL-15Rα for use in promoting the maturation and export of T cells from the thymus to peripheral tissues, including peripheral lymphoid and non-lymphoid tissues.

[0038] In another aspect, the invention provides IL-15/IL-15Rα polypeptide complexes for use in promoting the maturation and export of T cells from the thymus to peripheral tissues, including peripheral lymphoid and non-lymphoid tissues.

[0039] In a related aspect, the invention provides a DNA vector encoding IL-15 and IL-15Rα for use in promoting repopulation of depleted lymphocytes in peripheral tissues and/or preventing, reducing and/or inhibiting lymphopenia.

[0040] In another aspect, the invention provides IL-15/IL-15Rα polypeptide complexes for use in promoting repopulation of depleted lymphocytes in peripheral tissues and/or preventing, reducing and/or inhibiting lymphopenia.

[0041] In another aspect, the invention provides stable cell lines that express IL-15/IL-15Rα polypeptides. In some embodiments, the stable cell line expresses IL-15/IL-15Rα in the form of a fusion protein. In some embodiments, the stable cell lines produce IL-15 and IL-15Rα as different molecules. In some embodiments, the stable cell lines produce IL-15 and secreted IL-15Rα deletions that lack the transmembrane anchor portion of the receptor. In some embodiments the stable cell lines produce IL-15 and fusions of IL15Rα to the an immunoglobulin Fc region. In some embodiments the stable cell lines produce IL-15 and IL-15Rα fusions to polypeptides able to direct binding of the fusion to the cell surface of specific cell types. In some embodiments the stable cell lines produce IL-15 and IL-15Rα fusions to polypeptides able to direct multimerization of the fusion.

[0042] Further embodiments are as described herein.

DEFINITIONS

[0043] The term "central lymphoid tissue" or "central lymphoid organ" refers to specialized lymphoid tissues where the production of new lymphocytes, or lymphopoiesis, takes place. For example, T cells develop and mature in the thymus or thymic tissue. B cells and natural killer (NK) cells develop in bone marrow tissue. *See*, *e.g.*, Chapter 7 of Janeway, *et al.*, *Immunobiology*, 2001, Garland Publishing, New York.

[0044] The term "peripheral lymphoid tissue" or "peripheral lymphoid organ" refers to peripheral tissues of highly organized architecture, with distinct areas of B cells and T cells. Newly produced lymphocytes leave the central lymphoid tissues, and are carried in the blood to the peripheral lymphoid tissues. Exemplary peripheral lymphoid tissues or organs include the spleen, lymph nodes, mucosal-associated lymphoid tissues (MALT), *e.g.*, tonsils and gut-associated lymphoid tissues (GALT), including Peyer's patches.

[0045] The term "mature lymphocyte" refers to a lymphocyte that is undergone selection and development to maturity in the central lymphoid tissue sufficient to circulate to

peripheral lymphoid tissues. With respect to T cells, a mature T cell is characterized by the expression of either CD4 or CD8, but not both (*i.e.*, they are single positive), and expression of CD3. With respect to B cells, a mature B cell is characterized by VDJ rearranged immunoglobulin heavy chain gene, VJ rearranged immunoglobulin light chain gene, and the surface expression of IgD and/or IgM. The mature B cell may also express CD19 and the IL-7 receptor on the cell surface.

[0046] The term "activated lymphocyte" refers to lymphocytes that have recognized an antigen bound to a MHC molecule and the simultaneous delivery of a co-stimulatory signal by a specialized antigen-presenting cell. Activation of lymphocytes changes the expression of several cell-surface molecules.

[0047] With respect to T cells, resting naive T cells express L-selectin, and low levels of other adhesion molecules such as CD2 and LFA-1. Upon activation of the T cell, expression of L-selectin is lost and, instead, increased amounts of the integrin VLA-4 are expressed. Activated T cells also express higher densities of the adhesion molecules CD2 and LFA-1, increasing the avidity of the interaction of the activated T cell with potential target cells, and higher densities of the adhesion molecule CD44. Finally, the isoform of the CD45 molecule expressed by activated cells changes, by alternative splicing of the RNA transcript of the CD45 gene, so that activated T cells express the CD45RO isoform that associates with the T-cell receptor and CD4. Also, with respect to cytokine production, resting T cells produce little or no IL-2 and the β and γ subunits of the IL-2 receptor. In contrast, activated T cells produce significant amounts IL-2 along with the α chain of the IL-2 receptor.

[0048] With respect to B cells, activated B cells have undergone isotype switching and secrete immunoglobulin. Naive B cells express cell-surface IgM and IgD immunoglobulin isotypes. In contrast, activated or memory B cells express and secrete IgG, IgA or IgE immunoglobulin isotypes.

[0049] The terms "output" or "migration" from a central lymphoid tissue refers to migration or export of mature lymphocytes from a central lymphocyte tissue to a peripheral tissue, including lymphoid and non-lymphoid peripheral tissues. Output includes the migration of mature T cells from the thymus and the migration of mature B cells and NK cells from the bone marrow.

[0050] The terms "treating" and "treatment" refer to delaying the onset of, retarding or reversing the progress of, or alleviating or preventing either the disease or condition to which the term applies, or one or more symptoms of such disease or condition.

[0051] The terms "lymphopenia" or "lymphocytopenia" or "lymphocytic leucopenia" interchangeably refer to an abnormally small number of lymphocytes in the circulating blood or in peripheral circulation. Quantitatively, lymphopenia can be described by various cutoffs. In some embodiments, a patient is suffering from lymphopenia when their circulating blood total lymphocyte count falls below about 600/mm^3. In some embodiments, a patient suffering from lymphopenia has less than about 2000/μL total circulating lymphocytes at birth, less than about 4500/μL total circulating lymphocytes at about age 9 months, or less than about 1000/μL total circulating lymphocytes patients older than about 9 months (children and adults). Lymphocytopenia has a wide range of possible causes, including viral (*e.g.*, HIV infection), bacterial (*e.g.*, active tuberculosis infection), and fungal infections; chronic failure of the right ventricle of the heart, Hodgkin's disease and cancers of the lymphatic system, leukemia, a leak or rupture in the thoracic duct, side effects of prescription medications including anticancer agents, antiviral agents, and glucocorticoids, malnutrition resulting from diets that are low in protein, radiation therapy, uremia, autoimmune disorders, immune deficiency syndromes, high stress levels, and trauma. Lymphopenia may also be of unknown etiology (*i.e.*, idiopathic lymphopenia). Peripheral circulation of all types of lymphocytes or subpopulations of lymphocytes (*e.g.*, CD4+ T cells) may be depleted or abnormally low in a patient suffering from lymphopenia. *See*, *e.g.*, The Merck Manual, 18th Edition, 2006, Merck & Co.

[0052] The term "native mammalian interleukin-15 (IL-15)" refers to any naturally occurring interleukin-15 nucleic acid and amino acid sequences of the IL-15 from a mammalian species. Those of skill in the art will appreciate that interleukin-15 nucleic acid and amino acid sequences are publicly available in gene databases, for example, GenBank through the National Center for Biotechnological Information on the worldwide web at ncbi.nlm.nih.gov. Exemplified native mammalian IL-15 nucleic acid or amino acid sequences can be from, for example, human, primate, canine, feline, porcine, equine, bovine, ovine, rodentia, murine, rat, hamster, guinea pig, etc. Accession numbers for exemplified native mammalian IL-15 nucleic acid sequences include NM_172174.2 (human preproprotein); NM_172175 (human); NM_000585.3 (human preproprotein); U19843 (macaque); DQ021912 (macaque); AB000555 (macaque); NM_214390 (porcine); DQ152967 (ovine); NM_174090 (bovine); NM_008357 (murine); NM_013129 (rattus); DQ083522 (water buffalo); XM_844053 (canine); DQ157452 (lagomorpha); and NM_001009207 (feline). Accession numbers for exemplified native mammalian IL-15 amino acid sequences include NP_000576.1 (human preproprotein); NP_751914 (human preproprotein);

CAG46804 (human); CAG46777 (human); AAB60398 (macaque); AAY45895 (macaque); NP_999555 (porcine); NP_776515 (bovine); AAY83832 (water buffalo); ABB02300 (ovine); XP_849146 (canine); NP_001009207 (feline); NP_037261 (rattus); and NP_032383 (murine).

[0053] The term "interleukin-15" or "IL-15" refers to a polypeptide that has at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% sequence identity to a native mammalian IL-15 amino acid sequence, or a nucleotide encoding such a polypeptide, is biologically active, meaning the mutated protein ("mutein") has functionality similar (75% or greater) to that of a native IL-15 protein in at least one functional assay. Functionally, IL-15 is a cytokine that regulates T cell and natural killer cell activation and proliferation. IL-15 and IL-2 share many biological activities, including binding to CD122, the IL-2β/IL-15β receptor subunit. The number of CD8+ memory cells is controlled by a balance between this IL-15 and IL-2. IL-15 induces the activation of JAK kinases, as well as the phosphorylation and activation of transcription activators STAT3, STAT5, and STAT6. IL-15 also increases the expression of apoptosis inhibitor BCL2L1/BCL-x(L), possibly through the transcription activation activity of STAT6, and thus prevents apoptosis. Two alternatively spliced transcript variants of the IL-15 gene encoding the same mature protein have been reported. Exemplified functional assays of an IL-15 polypeptide include proliferation of T-cells (*see, for example*, Montes, *et al.*, *Clin Exp Immunol* (2005) 142:292), and activation of NK cells, macrophages and neutrophils. Methods for isolation of particular immune cell subpopulations and detection of proliferation (*i.e.*, ^{3}H-thymidine incorporation) are well known in the art. Cell-mediated cellular cytotoxicity assays can be used to measure NK cell, macrophage and neutrophil activation. Cell-mediated cellular cytotoxicity assays, including release of isotopes (^{51}Cr), dyes (*e.g.*, tetrazolium, neutral red) or enzymes, are also well known in the art, with commercially available kits (Oxford Biomedical Research, Oxford, M; Cambrex, Walkersville, MD; Invitrogen, Carlsbad, CA). IL-15 has also been shown to inhibit Fas mediated apoptosis (*see*, Demirci and Li, *Cell Mol Immunol* (2004) 1:123). Apoptosis assays, including for example, TUNEL assays and annexin V assays, are well known in the art with commercially available kits (R&D Systems, Minneapolis, MN). *See also*, Coligan, *et al.*, Current Methods in Immunology, 1991-2006, John Wiley & Sons.

[0054] The term "native mammalian interleukin-15 Receptor alpha (IL15Rα)" refers to any naturally occurring interleukin-15 receptor alpha nucleic acid and amino acid sequences of the IL-15 receptor alpha from a mammalian species. Those of skill in the art will appreciate that interleukin-15 receptor alpha nucleic acid and amino acid sequences are publicly

available in gene databases, for example, GenBank through the National Center for Biotechnological Information on the worldwide web at ncbi.nlm.nih.gov. Exemplified native mammalian IL-15 receptor alpha nucleic acid or amino acid sequences can be from, for example, human, primate, canine, feline, porcine, equine, bovine, ovine, rodentia, murine, rat, hamster, guinea pig, etc. Accession numbers for exemplified native mammalian IL-15 nucleic acid sequences include NM_172200.1 (human isoform 2); and NM_002189.2 (human isoform 1 precursor). Accession numbers for exemplified native mammalian IL-15 amino acid sequences include NP_751950.1 (human isoform 2); and NP_002180.1 (human isoform 1 precursor).

[0055] The term "interleukin-15 receptor alpha" or "IL15Rα" refers to a polypeptide that has at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% sequence identity to a native mammalian IL15Ra amino acid sequence, or a nucleotide encoding such a polypeptide, is biologically active, meaning the mutated protein ("mutein") has functionality similar (75% or greater) to that of a native IL15Rα protein in at least one functional assay. IL15Rα is a cytokine receptor that specifically binds IL15 with high affinity. One functional assay is specific binding to a native IL-15 protein.

[0056] The term "soluble IL-15 Receptor alpha" or "sIL-15α" refers to forms of IL-15 Receptor alpha lacking the transmembrane anchor portion of the receptor and thus able to be secreted out of the cell without being anchored to the plasma membrane. Exemplary sIL-15α include aa 31-205 and aa31-185 of the native IL-15 Receptor alpha.

[0057] An "IL-15Rα Fc fusion" or an "IL-15Rα fused to an Fc region" as used herein refers to forms of IL-15Rα in which the protein is fused to one or more domains of an Fc region of an immunoglobulin, typically of an IgG immunoglobulin. The Fc region comprises the CH2 and CH3 domains of the IgG heavy chain and the hinge region. The hinge serves as a flexible spacer between the two parts of the Fc-Fusion protein, allowing each part of the molecule to function independently. The use of Fc fusions is known in the art (see, *e.g.,* U.S. Patent Nos. 7,754,855; 5,480,981; 5,808,029; Wo7/23614; Wo98/28427 and references cited therein. Fc fusion proteins can include variant Fc molecules (*e.g.,* as described in U.S. Patent No. 7,732,570). Fc fusion proteins can be soluble in the plasma or can associate to the cell surface of cells having specific Fc receptors.

[0058] The term "nucleic acid" refers to deoxyribonucleotides or ribonucleotides and polymers thereof in either single- or double-stranded form. The term encompasses nucleic acids containing known nucleotide analogs or modified backbone residues or linkages, which

are synthetic, naturally occurring, and non-naturally occurring, which have similar binding properties as the reference nucleic acid, and which are metabolized in a manner similar to the reference nucleotides. Examples of such analogs include, without limitation, phosphorothioates, phosphoramidates, methyl phosphonates, chiral-methyl phosphonates, 2-O-methyl ribonucleotides, peptide-nucleic acids (PNAs).

[0059] Unless otherwise indicated, a particular nucleic acid sequence also implicitly encompasses conservatively modified variants thereof (e.g., degenerate codon substitutions) and complementary sequences, as well as the sequence explicitly indicated. Degenerate codon substitutions can be achieved by generating sequences in which the third position of one or more selected (or all) codons is substituted with mixed-base and/or deoxyinosine residues (Batzer *et al.*, *Nucleic Acid Res.* 19:5081 (1991); Ohtsuka *et al.*, *J. Biol. Chem.* 260:2605-2608 (1985); Rossolini et al., *Mol. Cell. Probes* 8:91-98 (1994)). The term nucleic acid is used interchangeably with gene, cDNA, mRNA, oligonucleotide, and polynucleotide.

[0060] Degenerate codon substitutions for naturally occurring amino acids are in Table 1.

TABLE 1

1st position (5′ end)	2nd position				3rd position (3′ end)
	U(T)	C	A	G	
U(T)	Phe	Ser	Tyr	Cys	U(T)
	Phe	Ser	Tyr	Cys	C
	Leu	Ser	STOP	STOP	A
	Leu	Ser	STOP	Trp	G
C	Leu	Pro	His	Arg	U(T)
	Leu	Pro	His	Arg	C
	Leu	Pro	Gln	Arg	A
	Leu	Pro	Gln	Arg	G
A	Ile	Thr	Asn	Ser	U(T)
	Ile	Thr	Asn	Ser	C
	Ile	Thr	Lys	Arg	A
	Met	Thr	Lys	Arg	G
G	Val	Ala	Asp	Gly	U(T)
	Val	Ala	Asp	Gly	C
	Val	Ala	Glu	Gly	A

1st position (5′ end)	2nd position				3rd position (3′ end)
	U(T)	C	A	G	
	Val	Ala	Glu	Gly	G

[0061] The terms "identical" or percent "identity," in the context of two or more nucleic acids or polypeptide sequences, refer to two or more sequences or subsequences that are the same or have a specified percentage of amino acid residues or nucleotides that are the same (i.e., about 70% identity, preferably 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or higher identity over a specified region (e.g., of a IL-15 or IL-15Rα sequence), when compared and aligned for maximum correspondence over a comparison window or designated region) as measured using a BLAST or BLAST 2.0 sequence comparison algorithms with default parameters described below, or by manual alignment and visual inspection (*see, e.g.*, NCBI web site or the like). Such sequences are then said to be "substantially identical." This definition also refers to, or can be applied to, the compliment of a test sequence. The definition also includes sequences that have deletions and/or additions, as well as those that have substitutions. As described below, the preferred algorithms can account for gaps and the like. Preferably, identity exists over a region that is at least about 25, 50, 75, 100, 150, 200 amino acids or nucleotides in length, and oftentimes over a region that is 225, 250, 300, 350, 400, 450, 500 amino acids or nucleotides in length or over the full-length of am amino acid or nucleic acid sequences.

[0062] For sequence comparison, typically one sequence acts as a reference sequence, to which test sequences are compared (here, an entire "native mammalian" IL-15 amino acid or nucleic acid sequence). When using a sequence comparison algorithm, test and reference sequences are entered into a computer, subsequence coordinates are designated, if necessary, and sequence algorithm program parameters are designated. Preferably, default program parameters can be used, or alternative parameters can be designated. The sequence comparison algorithm then calculates the percent sequence identities for the test sequences relative to the reference sequence, based on the program parameters.

[0063] A preferred example of algorithm that is suitable for determining percent sequence identity and sequence similarity are the BLAST algorithms, which are described in Altschul *et al., Nuc. Acids Res.* 25:3389-3402 (1977) and Altschul *et al., J. Mol. Biol.* 215:403-410 (1990), respectively. BLAST software is publicly available through the National Center for Biotechnology Information on the worldwide web at ncbi.nlm.nih.gov/. Both default

parameters or other non-default parameters can be used. The BLASTN program (for nucleotide sequences) uses as defaults a wordlength (W) of 11, an expectation (E) of 10, M=5, N=-4 and a comparison of both strands. For amino acid sequences, the BLASTP program uses as defaults a wordlength of 3, and expectation (E) of 10, and the BLOSUM62 scoring matrix (*see* Henikoff & Henikoff, *Proc. Natl. Acad. Sci. USA* 89:10915 (1989)) alignments (B) of 50, expectation (E) of 10, M=5, N=-4, and a comparison of both strands.

[0064] The term "GC content" refers to the percentage of a nucleic acid sequence comprised of deoxyguanosine (G) and/or deoxycytidine (C) deoxyribonucleosides, or guanosine (G) and/or cytidine (C) ribonucleoside residues.

[0065] The term "operably linked" refers to a functional linkage between a first nucleic acid sequence and a second nucleic acid sequence, such that the first and second nucleic acid sequences are transcribed into a single nucleic acid sequence. Operably linked nucleic acid sequences need not be physically adjacent to each other. The term "operably linked" also refers to a functional linkage between a nucleic acid expression control sequence (such as a promoter, or array of transcription factor binding sites) and a transcribable nucleic acid sequence, wherein the expression control sequence directs transcription of the nucleic acid corresponding to the transcribable sequence.

[0066] Amino acids can be referred to herein by either their commonly known three letter symbols or by the one-letter symbols recommended by the IUPAC-IUB Biochemical Nomenclature Commission. Nucleotides, likewise, can be referred to by their commonly accepted single-letter codes.

[0067] "Conservatively modified variants" as used herein applies to amino acid sequences. One of skill will recognize that individual substitutions, deletions or additions to a nucleic acid, peptide, polypeptide, or protein sequence which alters, adds or deletes a single amino acid or a small percentage of amino acids in the encoded sequence is a "conservatively modified variant" where the alteration results in the substitution of an amino acid with a chemically similar amino acid. Conservative substitution tables providing functionally similar amino acids are well known in the art. Such conservatively modified variants are in addition to and do not exclude polymorphic variants, interspecies homologs, and alleles of the invention.

[0068] The following eight groups each contain amino acids that are conservative substitutions for one another:

1) Alanine (A), Glycine (G);

2) Aspartic acid (D), Glutamic acid (E);

3) Asparagine (N), Glutamine (Q);

4) Arginine (R), Lysine (K);

5) Isoleucine (I), Leucine (L), Methionine (M), Valine (V);

6) Phenylalanine (F), Tyrosine (Y), Tryptophan (W);

7) Serine (S), Threonine (T); and

8) Cysteine (C), Methionine (M) (see, e.g., Creighton, Proteins (1984)).

[0069] The terms "mammal" or "mammalian" refer to any animal within the taxonomic classification mammalia. A mammal can refer to a human or a non-human primate. A mammal can refer to a domestic animal, including for example, canine, feline, rodentia, including lagomorpha, murine, rattus, Cricetinae (hamsters), etc. A mammal can refer to an agricultural animal, including for example, bovine, ovine, porcine, equine, etc.

[0070] The term "therapeutically effective amount" refers to the dose of a therapeutic agent or agents sufficient to achieve the intended therapeutic effect with minimal or no undesirable side effects. A therapeutically effective amount can be readily determined by a skilled physician, *e.g.*, by first administering a low dose of the pharmacological agent(s) and then incrementally increasing the dose until the desired therapeutic effect is achieved with minimal or no undesirable side effects.

[0071] The term "supraphysiologic levels" refers to levels of IL-15 in a particular tissue, *e.g.*, blood, plasma, serum, thymus, that are above naturally occurring physiologic levels. Supraphysiologic levels of IL-15 in a tissue can also be achieved when the concentration of IL-15 in that tissue is sustained above naturally occurring levels for an extended period of time, *e.g..*, for consecutive days or weeks or for the duration of therapeutic treatment. For example, IL-15 DNA or protein can be administered at a dose sufficient to achieve plasma levels of IL-15 of about 1 to 1000 ng/ml, for example, plasma levels of IL-15 of about 10 to 1000 ng/ml. The IL-15 and IL-15Rα can be delivered in equimolar amounts. Alternatively, an IL-15/IL-15Rα protein complex can be administered at a dose of about 0.01 to 0.5 mg/kg.

[0072] The term "co-administer" refers to the presence of two pharmacological agents, *e.g.*, IL-15 and IL-15Rα, in the blood at the same time. The two pharmacological agents can be administered concurrently or sequentially.

[0073] The term "consisting essentially of" refers to administration of the pharmacologically active agents expressly recited, *e.g.*, IL-15 and IL-15Rα, and excludes pharmacologically active agents not expressly recited, *e.g.*, an antigen. The term consisting essentially of does not exclude pharmacologically inactive or inert agents, *e.g.*, physiologically acceptable carriers or excipients.

BRIEF DESCRIPTION OF THE DRAWINGS

[0074] Figure 1 illustrates a schematic of the mutual stabilization of IL-15 and IL-15α.

[0075] Figure 2 illustrates the effects of systemic co-administration of polynucleotides expressing IL-15 and IL-15Rα on spleen weight (top panel), thymus weight (middle panel) and percentage of lymphocytes in the bone marrow (bottom panel).

[0076] Figure 3 illustrates the effects of systemic co-administration of polynucleotides expressing IL-15 and IL-15Rα on T cell maturation in the thymus. Double positive CD4+CD8+ T cells are decreased with a concomitant increase in CD3high single positive T cells (*i.e.*, CD4+ or CD8+ T cells).

[0077] Figure 4 illustrates the migration of dividing carboxyfluorescein succinimidyl ester ("CFSE")-loaded thymocytes to the lung in IL-15-treated and untreated control mice (upper panels). The lower panels show increased expression of CD122 (IL-2Rβ/IL-15Rβ) on lymphocytes, *e.g.*, total T cells and CD+ T cells, in the lung.

[0078] Figure 5 illustrates lymphocyte reconstitution in lung tissue of IL-15 knock-out (KO) mice treated with plasmid DNA encoding IL-15/IL-15Rα compared to untreated control KO mice.

[0079] Figure 6 provides a schematic of the time course of a lymphodepletion experiment.

[0080] Figure 7 illustrates spleen weight over time after cyclophosphamide (Cyp) and Cyp + IL-15/IL-15Rα administration.

[0081] Figure 8 illustrates the increase in lung NK cells after Cyp administration.

[0082] Figure 9 illustrates the increase in lung T cells in the presence of IL-15/IL-15Rα.

[0083] Figure 10 illustrates that CD8+ T cells partially recover after IL-15/IL-15Rα administration.

[0084] Figure 11 illustrates the increase in lung CD8+ T cells in the presence of IL-15/IL-15Rα as reflected in the change of the ratio of CD8+ to CD4+ T cells after IL-15 administration.

[0085] Figure 12 illustrates a T cell analysis in the spleen after Cyp and IL-15/IL-15Rα administration.

[0086] Figure 13 illustrates the full recovery of bone marrow T cells after IL-15/IL-15Rα administration.

[0087] Figure 14 illustrates the IL-15/IL-15Rα treatment protocol for lymphopenic mice used in Example 3.

[0088] Figure 15 illustrates that a single administration of IL-15/IL-15sRα-encoding DNA is sufficient for the complete recovery of NK cells in spleen and lung 5 days after DNA injection.

[0089] Figure 16 illustrates that IL-15/IL-15sRα administration promotes the recovery of CD8 T cells within 10 days after treatment, without significantly affecting the recovery of CD4 T cells.

[0090] Figure 17 illustrates that high levels of circulating IL-15/IL-15sRα promote a transient increase in the Teffector/Treg ratio after lymphoablation.

[0091] Figure 18 illustrates IL-15 levels in serum following hydrodynamic delivery of DNA vectors expressing different forms of IL-15.

[0092] Figure 19 illustrates CD25 expression on the surface of spleen T cells after IL-15/IL-15Rα DNA delivery.

[0093] Figure 20 illustrates expression of CD62L on the surface of spleen T cells after IL-15/IL-15Rα DNA delivery.

[0094] Figure 21 illustrates express of CD44 on the surface of spleen T cells after IL-15/IL-5Rα DNA delivery.

[0095] Figure 22 illustrates a protocol (Example 5) for administration of purified IL-15/IL-15sRα *in vivo*.

[0096] Figure 23 illustrates that purified IL-15/IL-15Rα is bioactive *in vivo*.

DETAILED DESCRIPTION

1. Introduction

[0097] The present invention is based, in part, on the surprising discovery that subjecting thymic tissue to supraphysiological levels of IL-15 promotes the maturation of T cells in the thymus from double positive CD4+CD8+ T cells to single positive (*i.e.*, CD4+ or CD8+) CD3high T cells, decreases the frequency of apoptotic thymocytes, and increases the migration of mature T cells from the thymus to peripheral tissues, including lymphoid and non-lymphoid peripheral tissues.

[0098] The present invention is further based, in part, on the surprising discovery that systemic administration of supraphysiological levels of IL-15 promotes the maturation and export of lymphocytes from central lymphoid tissues (*e.g.*, in the thymus and bone marrow) to peripheral tissues, including lymphoid and non-lymphoid peripheral tissues.

2. Methods of Promoting Maturation of Lymphocytes in a Central Lymphoid Organ and the Migration of the Lymphocytes to Peripheral Tissues

[0099] The present invention provides methods of promoting T cell maturation in the thymus, decreasing apoptosis of T cells in the thymus and promoting migration or output of mature T cells from the thymus, by contacting the thymus tissue with supraphysiological levels of IL-15. The thymic tissue can be *in vivo* or *in vitro*.

[0100] When the IL-15 is administered *in vivo*, it is provided to a subject or patient or individual in need thereof. The subject can be any mammal. In some embodiments, the mammal is a human or a non-human primate. Subjects who will benefit from the present methods have a deficiency of mature thymocytes and/or other lymphocytes in peripheral tissues, including lymphoid and non-lymphoid peripheral tissues. In some embodiments, the subject is immunodeficient or has lymphopenia. In some embodiments, the subject has a drug-induced immunodeficiency, *e.g.*, due to anticancer drugs. In some embodiments, the subject has an immunodeficiency secondary to a disease, *e.g.*, HIV infection. In some embodiments, the subject may have a genetic mutation that results in a non-functional IL-15 or non-functional IL-15 receptor subunit (*e.g.*, IL-15Rα, IL-15Rβ, or IL-15Rγ).

[0101] Sustained exposure of thymic tissue to supraphysiological levels of IL-15 promotes the maturation of double positive T cells. IL-15 promotes the terminal differentiation of the thymocytes to single positive T cells expressing either CD4 or CD8. The mature T cells also may express CD122 (also known as the beta subunit of IL-2/IL-15 receptor). The mature T

cells may also express high levels of the CD3 surface protein. IL-15-induced maturation of T cells also corresponds to a reduction in the frequency of immature T cells that undergo apoptosis. By contacting the thymic tissue with supraphysiologic levels of IL-15, the CD4+CD8+ double positive and CD3low T cells can be substantially eliminated as the cells mature into single positive CD3high T cells. After exposure to supraphysiologic levels of IL-15, at least 60%, 70%, 80%, 90%, 95% or more of the T cells are CD4+ or CD8+ single positive CD3high T cells.

[0102] IL-15-induced maturation of T cells in thymus tissue also promotes the migration of the mature T cells to the peripheral tissues, including lymphoid and non-lymphoid peripheral tissues. The mature T cells leaving the thymus may or may not be activated. For example, after about 2, 3, 4, 5, 6, 7, 8, 9, 10 or more days exposure to supraphysiologic levels of IL-15, the thymus organ may have decreased in size, *e.g.*, by at least about 30%, 40%, 50%, or more, due to IL-15-induced thymic output.

[0103] Systemic administration of supraphysiologic levels of IL-15, *e.g.*, sustained over the course of *e.g.*, about 2, 3, 4, 5, 6, 7, 8, 9, 10 or more days, also promotes the maturation and migration of lymphocytes, including NK cells, from bone marrow. For example, after about 2, 3, 4, 5, 6, 7, 8, 9, 10 or more days exposure to supraphysiologic levels of IL-15, the percentage of lymphocytes in the bone marrow may have decreased, *e.g.*, by at least about 50%, 60%, 70%, 80%, or more, due to IL-15-induced lymphocyte output from bone marrow.

[0104] At the same time that the number of lymphocytes decrease in the central lymphoid tissues, *i.e.*, in the thymus and bone marrow, the number of lymphocytes in peripheral lymphoid tissues, *e.g.*, spleen, lymph node, mucosal-associated lymphoid tissues (MALT), e.g., tonsils and/or gut-associated lymphoid tissues (GALT), including Peyer's patches, increases. Furthermore, the number of lymphocytes in peripheral non-lymphoid tissues, including the lung, liver, kidney, skin, and other tissues, also increases. In some embodiments, the administration of supraphysiologic levels of IL-15 increases the number of lymphocytes, including T cells, B cells and NK cells, in the blood.

3. Methods of treating lymphopenia

[0105] As explained above, in one aspect, the invention is based on the discovery that systemic administration of supraphysiological levels of IL-15 promotes the maturation and export of lymphocytes from central lymphoid tissues (e.g., in the thymus and bone marrow) to peripheral tissues, including lymphoid and non-lymphoid peripheral tissues.

[0106] Accordingly, the invention provides methods for preventing, reducing and inhibiting the depletion of lymphocytes, including T cells, B cells and natural killer (NK) cells, in peripheral circulation or tissues by systemic administration of IL-15 to a subject in need thereof. The present invention also provides methods for accelerating the recovery from and shortening the time period of depletion of lymphocytes, including T cells, B cells and natural killer (NK) cells, in peripheral circulation or tissues by systemic administration of IL-15 to a subject in need thereof.

[0107] The subject, patient or individual can be any mammal. In some embodiments, the mammal is a human or a non-human primate. In some embodiments, the individual is a domestic mammal (*e.g.*, a canine or feline), a laboratory mammal (*e.g.*, a mouse, a rat, a rabbit, a hamster), or an agricultural mammal (*e.g.*, a bovine, a porcine, a ovine, an equine). Subjects who will benefit from the present methods either already have or will have (*e.g.*, as a result of a course of drug treatment) a deficiency of mature lymphocytes in peripheral circulation or tissues, including lymphoid and non-lymphoid peripheral tissues. In some embodiments, the subject is immunodeficient or has lymphopenia. For the purposes of treatment, the patient is already suffering abnormally low levels of circulating lymphocytes. For the purposes of prevention, the patient may have normal levels of peripheral lymphocytes and is likely to experience lymphodepletion, *e.g.*, as a result of a chemotherapeutic treatment.

[0108] Standards for diagnosing lymphopenia are known in the art, and can be made by any trained physician. In some embodiments, the patient has a circulating blood total lymphocyte count that is below about 600/mm^3. In some embodiments, the patient has a circulating blood total lymphocyte count that is less than about 2000/μL total circulating lymphocytes at birth, less than about 4500/μL total circulating lymphocytes at about age 9 months, or less than about 1000/μL total circulating lymphocytes patients older than about 9 months (children and adults). *See, e.g.*, The Merck Manual, 18th Edition, 2006, Merck & Co.

[0109] The origins or etiology of the depletion or abnormally low can be for any reason. Lymphocytopenia has a wide range of possible causes, including viral (e.g., HIV infection), bacterial (*e.g.*, active tuberculosis infection), and fungal infections; chronic failure of the right ventricle of the heart, Hodgkin's disease and cancers of the lymphatic system, leukemia, a leak or rupture in the thoracic duct, side effects of prescription medications including anticancer agents, antiviral agents, and glucocorticoids, malnutrition resulting from diets that are low in protein, radiation therapy, uremia, autoimmune disorders, immune deficiency syndromes, high stress levels, and trauma. The lymphopenia may also be of unknown etiology (*i.e.*, idiopathic lymphopenia).

[0110] The lymphocyte depletion may involve total lymphocytes (*e.g.*, T cells, B cells, and NK cells, etc.), or may only involve a subpopulation of total lymphocytes (one or more of T cells, CD4+ T cells, CD8+ T cells, B cells, NK cells).

[0111] In some embodiments, the patient has a disease that causes depletion of peripheral circulating lymphocytes. For example, the patient may suffer from a cancer, including Hodgkin's disease and cancers of the lymphatic system, leukemia; a viral infection, including HIV or hepatitis virus. In some embodiments, the patient is receiving chemotherapy, *e.g.*, an anticancer agent, an antiviral or antiretroviral agent, or a glucocorticoid, that causes depletion of peripheral circulating lymphocytes. Exemplary pharmacological agents that can cause lymphodepletion include without limitation vinblastine, fludarabine, aclarubicin, doxorubicin, exemestane, alefacept, alemtuzumab, chloramphenicol, pamidronate, idarubicin and cyclophosphamide.

[0112] In some embodiments, the subject may have a genetic mutation that results in a non-functional IL-15 or non-functional IL-15 receptor subunit (e.g., IL 15Rα, IL 15Rβ, or IL 15Rγ).

4. IL-15

[0113] The IL-15 for use in the invention can be any physiologically active (*i.e.*, functional) IL-15. The IL-15 can be delivered as a polypeptide or a polynucleotide encoding IL-15. The IL-15 can be full-length or a physiologically active fragment thereof, for example, an IL-15 fragment that retains binding to IL-15Rα and/or IL-15Rβ, or an IL-15 fragment that promotes proliferation and/or maturation of T cells. In some embodiments, the delivered or expressed IL-15 polypeptide has one or more amino acids that are substituted, added or deleted, while still retaining the physiological activity of IL-15. In some embodiments, the delivered or expressed IL-15 shares at least 90%, 93%, 95%, 97%, 98%, 99% or 100% amino acid sequence identity with a wild-type IL-15, *e.g.*, SEQ ID NO:2. In some embodiments, the polynucleotide encoding IL-15 shares at least 90%, 93%, 95%, 97%, 98%, 99% or 100% nucleic acid sequence identity with a wild-type IL-15 coding sequence, *e.g.*, SEQ ID NO:1.

[0114] The polynucleotide encoding IL-15 may have one or more codons altered for improved expression. In some embodiments, the polynucleotide encoding IL-15 shares at least 90%, 93%, 95%, 97%, 98%, 99% or 100% nucleic acid sequence identity with a wild-type IL-15 coding sequence, *e.g.*, SEQ ID NO:3. In some embodiments, the polynucleotide encoding IL-15 shares at least 96%, 97%, 98%, 99% or 100% nucleic acid sequence identity

with a wild-type IL-15 coding sequence, *e.g.*, SEQ ID NO:4. Polynucleotides encoding IL-15 which have altered codons for improved expression are described, *e.g.*, in WO 2007/084342 and in WO 2004/059556, the entire disclosures of each of which are hereby incorporated herein by reference for all purposes.

[0115] The polynucleotide encoding IL-15 can be operably linked to polynucleotide encoding a native signal peptide sequence, *e.g.*, the long IL-15 signal peptide sequence (LSP) or the short IL-15 signal peptide sequence (SSP). In some embodiments, the nucleic acid sequence encoding a native IL-15 signal peptide is replaced with a nucleic acid sequence encoding a signal peptide from a heterologous protein. The heterologous protein can be, for example, from tissue plasminogen activator (tPA), growth hormone, granulocyte-macrophage colony stimulating factor (GM-CSF) or an immunoglobulin (*e.g.*, IgE). An example of a human GMCSF-IL-15 fusion is provided in SEQ ID NO:18. In some embodiments, the nucleic acid encoding the IL-15 is operably linked to a nucleic acid encoding an RNA export element, for example a CTE or RTEm26CTE.

[0116] Preferably, the IL-15 is administered as a heterodimer with IL-15Rα. One or both of the IL-15 and the IL-15Rα can be delivered as a polypeptide. One or both of the IL-15 and the IL-15Rα can be delivered as a polynucleotide. In one embodiment, the IL-15 and the IL-15Rα are co-administered as polypeptides. In one embodiment, an IL-15 polypeptide is co-administered with a polynucleotide encoding IL-15Rα. In one embodiment, an IL-15Rα polypeptide is co-administered with a polynucleotide encoding IL-15.

[0117] The administered IL-15Rα can be any physiologically active (*i.e.*, functional) IL-15Rα. The IL-15Rα can be delivered as a polypeptide or a polynucleotide encoding IL-15Rα. The IL-15Rα can be full-length or a physiologically active fragment thereof, for example, an IL-15Rα fragment that retains specific binding to IL-15. Further, the IL-15Rα, *e.g.,* a fragment that retains specific binding to IL-15 and lacks the transmembrane anchor region, can be fused to an Fc region. In some embodiments, the delivered or expressed IL-15Rα polypeptide has one or more amino acids that are substituted, added or deleted, while still retaining the physiological activity of IL-15Rα. In some embodiments, the delivered or expressed IL-15 shares at least 90%, 93%, 95%, 97%, 98%, 99% or 100% amino acid sequence identity with a wild-type IL-15Rα, *e.g.*, SEQ ID NO:5 or SEQ ID NO:7. In some embodiments, the polynucleotide encoding IL-15 shares at least 90%, 93%, 95%, 97%, 98%, 99% or 100% nucleic acid sequence identity with a wild-type IL-15 coding sequence, *e.g.*, SEQ ID NO:6 or SEQ ID NO:8.

[0118] The polynucleotide encoding IL-15Rα may have one or more codons altered for improved expression. In some embodiments, the polynucleotide encoding IL-15Rα shares at least 90%, 93%, 95%, 97%, 98%, 99% or 100% nucleic acid sequence identity with a wild-type IL-15Rα coding sequence, *e.g.*, SEQ ID NO:9 or SEQ ID NO:11. Polynucleotides encoding IL-15Rα which have altered codons for improved expression are described, *e.g.*, in WO 2007/084342.

[0119] The polynucleotide encoding IL-15Rα can be operably linked to polynucleotide encoding a native signal peptide sequence. In some embodiments, the nucleic acid sequence encoding a native IL-15Rα signal peptide is replaced with a nucleic acid sequence encoding a signal peptide from a heterologous protein. The heterologous protein can be, for example, from tissue plasminogen activator (tPA), growth hormone, granulocyte-macrophage colony stimulating factor (GM-CSF) or an immunoglobulin (*e.g.*, IgE). In some embodiments, the nucleic acid encoding the IL-15Rα is operably linked to a nucleic acid encoding an RNA export element, for example a CTE or RTEm26CTE.

[0120] In some embodiments, the IL-15Rα can be in the form of an Fc fusion protein. Examples of sIL-15Rα polypeptide sequences are shown in SEQ ID NO:17 and SEQ ID NO:20. Typically, such proteins are secreted and can be found soluble in the plasma, or they can be associated with the surface of cells expressing the Fc receptor for the Fc region of the fusion protein. Different fragments of IL-15Rα can be fused to the Fc region. Two examples of functional fusions are provided as SEQ ID NO:17 and SEQ ID NO:20, containing 205 or 200 amino acids within the IL-15Rα region. In some embodiments, the IL-15Rα region of the fusion protein can be released by proteolytic cleavage. In some embodiments, I-L15Rα functional region of the protein is linked to a polypeptide that is able to bind specific cell types via surface receptors. In some embodiments, the IL15-Rα Fc fusion protein shares at least 95%, 96%, 97%, 98%, 99% or 100% amino acid sequence identity with a polypeptide selected from the group consisting of SEQ ID NO:17 and SEQ ID NO:20.

[0121] In some embodiments, a polynucleotide encoding IL-15 is co-administered with a polynucleotide encoding IL-15Rα. The polynucleotide encoding IL-15 and the polynucleotide encoding IL-15Rα can be administered on the same vector or on separate vectors. Preferably the polynucleotide encoding IL-15 is co-administered with a polynucleotide encoding IL-15Rα are on the same vector. An example of a plasmid that encodes an IL-15Rα-Fc fusion having a polypeptide sequence of SEQ ID NO:17 and a human GM-CSF signal peptide-IL-15 of SEQ ID NO:18 is provided in SEQ ID NO:16. A

second example of a plasmid that encodes an IL-15Rα-Fc fusion having a polypeptide sequence of SEQ ID NO:20 and a human GM-CSF signal peptide-IL-15 of SEQ ID NO:18 is provided in SEQ ID NO:19.In some embodiments, the administered vector shares at least 95%, 97%, 98%, 99% or 100% nucleic acid sequence identity with a plasmid vector selected from the group consisting of SEQ ID NO:13, SEQ ID NO:14, SEQ ID NO:15, SEQ ID NO:16, and SEQ ID NO:19.

[0122] It is understood by one skilled in the art that expression vectors, promoters, polyadenylation signals, and secretory peptides alternatives to those in the example sequences provided herein can be used for the expression of the optimized IL-15 and IL-15 Receptor alpha.

[0123] For the purposes of the present methods, the IL-15 is not being used as an adjuvant to enhance the immune response against a particular antigen. Therefore, in the present methods, the IL-15 is administered without an antigen. Stated another way, the IL-15 is not co-administered with an antigen.

[0124] The IL-15 (and the IL-15Rα) are administered at a dose sufficient to achieve supraphysiological levels of IL-15 systemically or in the target tissue, *e.g.*, thymus, for the desired time period. The desired time period can be hours, days, weeks, or longer if necessary. In some embodiments, supraphysiological levels of IL-15 are sustained throughout the duration of treatment or until a desired therapeutic endpoint is achieved, *e.g.*, the repopulation of peripheral tissues with lymphocytes. In some embodiments, the IL-15 is administered one time, as a bolus. In some embodiments, the IL-15 is administered two or more times. When administered multiple times, the IL-15 can be administered daily, weekly, bi-weekly, monthly, or as needed to sustain supraphysiological levels of IL-15 systemically or in the target tissue.

[0125] In embodiments where the IL-15 (and the IL-15Rα) are administered as a polypeptide, typical dosages can range from about 0.1 mg/kg body weight up to and including about 0.5 mg/kg body weight. In some embodiments, the dose of polypeptide is about 0.01, 0.02, 0.05, 0.08, 0.1, 0.2, 0.3, 0.4, 0.5 mg/kg body weight.

[0126] In embodiments where the IL-15 (and the IL-15Rα) are administered as a polynucleotide, dosages are sufficient to achieve plasma levels of IL-15 of about 1 to 1000 ng/ml, for example, plasma levels of IL-15 of about 10 to 1000 ng/ml. Such a range of plasma concentrations can be achieved, *e.g.*, after intramuscular electroporation of about 0.1

mg IL-15/IL-15sRα expressing DNA plasmid per kg body weight.. In some embodiments, the dose of nucleic acid is about 0.02, 0.05, 0.1, 0.2, 0.5 mg/kg body weight.

[0127] The IL-15 can be administered by a route appropriate to effect systemic supraphysiological levels of IL-15 or supraphysiological levels of IL-15 in the target tissue, *e.g.*, thymus. When co-administered with IL-15Rα, the IL-15 and the IL-15Rα can be administered via the same or different routes. In some embodiments, the IL-15 (and the IL-15Rα) are administered systemically, including without limitation, enterally (*i.e.*, orally) or parenterally, *e.g.*, intravenously, intramuscularly, subcutaneously, intradermally, intranasally, or inhalationally. In some embodiments, the IL-15 (and the IL-15Rα) are administered locally, for example, intrathymically or directly into the bone marrow.

[0128] For treatment of lymphopenia, systemic administration of IL-15 promotes and accelerates the repopulation of peripheral lymphocyte populations. After administration of IL-15, the peripherally circulating lymphocytes or lymphocyte subpopulations can be at least 80%, 85%, 90% or 95% of levels considered to be normal in a healthy individual. In some embodiments, the lymphocytes or lymphocyte subpopulations are completely repopulated to normal levels. In some embodiments, the repopulation of lymphocytes is days or weeks faster in an individual who received administration of IL-15 in comparison to an individual who did not receive administration of IL-15.

[0129] Systemic administration of IL-15 also prevents, reduces or inhibits lymphocyte depletion in peripheral circulation, *e.g.*, caused by chemotherapy or radiation therapy. After administration of IL-15, the peripherally circulating lymphocytes or lymphocyte subpopulations can be maintained at levels of at least 70%, 75%, 80%, 85%, 90% or 95% of normal levels. In some embodiments, the lymphocytes or lymphocyte subpopulations are maintained at normal levels.

[0130] In some embodiments, the IL-15 is co-administered with a chemotherapeutic agent that causes or may cause lymphopenia or lymphocyte depletion in peripheral tissues. The chemotherapeutic agent may be an anticancer agent or an antiviral agent. In some embodiments, the IL-15 is administered after a course of treatment with a chemotherapeutic agent that causes or may cause lymphopenia or lymphocyte depletion in peripheral tissues. In some embodiments, the IL-15 is administered prior to, during or after a course of radiation therapy.

EXAMPLES

The following examples are offered to illustrate, but not to limit the claimed invention.

Example 1: Systemic Administration of IL-15 Promotes Maturation of T cells in the Thymus and the Migration of T cells to Peripheral Tissues

[0131] IL-15/IL-15Rα DNA was expressed systemically and locally at various levels in either normal or IL-15 knockout (KO) mice to further understand IL-15 biology. *See*, Bergamaschi, *et al.*, (2008) *J Biol Chem* 283:4189-4199. Supraphysiologic levels of IL-15/IL-15Rα in normal mice have rapid and profound effects in many tissues. There is a rapid and reversible increase in the size of spleen, whereas the thymus becomes smaller and bone marrow lymphocyte numbers decrease (Figure 2). We have previously shown that spleen and lymph node size increase is proportional to the amount of IL-15 in the plasma. *See*, Bergamaschi, *et al.*, (2008) *J Biol Chem* 283:4189-4199. The kinetics and composition of lymphocytes in many tissues were studied using 10 parameter flow cytometry, as well as adoptive transfer of cells and *in vivo* labeling. Our results underscore the strong effects of IL-15 at all steps of lymphocyte development, as also suggested by many investigators. *Reviewed in*, *e.g.*, Boyman, *et al.*, (2007) *Curr Opin Immunol* 19:320-326: Sprent, *et al.*, (2008) *Immunol Cell Biol* 86:312-319; Sprent and Surh, (2003) *Immunol Lett* 85:145-149; Surh, *et al.*, (2006) *Immunol Rev* 211:154-163; Surh and Sprent, (2005) *Semin Immunol* 17:183-191; and Surh and Sprent, (2008) *Immunity* 29:848-862. However, prior to the present invention, the effects of IL-15 in the thymus have not been elucidated. Our results indicate that IL-15 stimulates the maturation of CD4+CD8+ double positive thymocytes into CD3high single positive T cells (Figure 3) and accelerates their rapid migration to the periphery (Figure 4). Seven days after *in situ* labeling of thymocytes, IL-15/IL-15Rα promoted their migration to the lung. In the presence of IL-15/IL-15Rα the lymphocytes in the lung have higher levels of IL-2/IL-15Rα (CD122, *see*, Figure 4, bottom) indicating that they are activated. These results are consistent with the notion that IL-15 promotes not only accelerated exit from the thymus, but also the migration to peripheral tissues and the activation of these lymphocytes.

[0132] Our results also show that, in addition to NK and memory CD8+ T cells that are profoundly affected, as expected, all lymphocytes including naïve and memory CD4 and CD8 cells, and B lymphocytes are also affected to either divide, migrate or be activated. This is in

agreement with the widespread (but not universal) expression of the IL-2/IL-15 betagamma receptor. The hierarchy of responsiveness of the lymphocyte subsets to IL-15 reflects the levels of CD122 (IL-2Rbeta) on their surface. *See*, Bergamaschi, *et al.*, (2008) *J Biol Chem* 283:4189-4199.

[0133] Our observations are further supported by experiments performed in an IL-15 KO model, to correct the lymphocyte defects by administering plasmid DNA encoding IL-15/IL-15Rα heterodimer. IL-15 KO mice are characterized by a decrease in total T cell count that preferentially affects CD8+ T cells, which are almost completely absent in peripheral tissues. We show that IL-15/IL-15Rα is able to repopulate non-lymphoid organs, such as lungs, with both mature CD4 and CD8 T lymphocytes. The increase in CD4 T cells upon IL-15/IL-15Rα treatment is 10-fold, while the increase in the CD8+ population is significantly greater, reaching 100-fold (Figure 5). These results underscore the feasibility of using IL-15/IL-15Rα DNA to correct defects associated with lymphopenia (*e.g.*, caused by total absence of IL-15 or of another etiology). Analysis of lymphocytes migrating in different organs in the presence of IL-15 suggests that many acquire rapidly a memory phenotype in the absence of antigen recognition and that IL-15 promotes re-entry of some lymphocytes into the thymus. The issue of lymphocyte re-entry in the thymus is controversial, and the study of IL-15 effects may contribute to the understanding of this phenomenon. *See*, Sprent and Surh (2009) *Immunol Cell Biol* 87:46-49; Bosco, *et al.*, (2009) *Immunol Cell Biol* 87:50-57; Agus, *et al.*, (1991) *J Exp Med* 173:1039-1046. Our preliminary data indicate that transfer of CFSE loaded thymocytes into normal mice results in homing into the thymus only in animals receiving IL-15.

[0134] We have found that IL-15 decreases the frequency of apoptotic thymocytes, mainly by promoting their terminal differentiation into mature single positive T cells. Our results after intrathymic injection of CFSE indicate that IL-15 increases thymic output, as reflected by the higher frequency of fully mature CFSE labeled T cells in the spleen and lung of IL-15 treated mice.

[0135] We have further observed that the enlarged spleen size upon IL-15 treatment is partially due to increased frequency of B lymphocytes, either by local proliferation, B cell migration from other compartments, or both. In addition, during in vivo experiments with adoptive transferred CFSE-labeled splenocytes we observed IL-15-induced proliferation of both CD4 naïve and memory T cells. In contrast to CD8+ T cells, which almost universally proliferate in the presence of IL-15, the CD4+ T cell responses appear to be restricted to a subset of cells.

Example 2: Correction of Cyclophosphamide-Induced Lymphopenia by IL-15/IL-15Rα DNA Administration

Summary

[0136] The present example shows the reversal of cyclophosphamide-induced lymphopenia in normal young mice by systemic administration of IL-15. One or two high doses of IL-15 were administered two (2) days (or two (2) and twelve (12) days) after cyclophosphamide by hydrodynamic DNA injection. The results show that mice recover faster from lymphopenia after IL-15 administration in comparison to control mice with cyclophosphamide-induced lymphopenia that did not receive IL-15. Lymphocytes recovered faster in peripheral tissues after IL-15 administration. NK cells were the first to recover, whereas T cells recovered in approximately one month. In the course of these studies, we discovered that two administrations of IL-15 improved T cell recovery over a single administration of IL-15. In addition, low and sustained levels of IL-15 provides for a more efficient repopulation of lymphocytes to the peripheral tissues in comparison to a single high dose. These results demonstrate that IL-15 is useful in treating and/or preventing lymphopenia.

Methods

Cyclophosphamide administration

[0137] Six-to-eight week old female Balb/c mice were obtained from Charles River Laboratory (Frederick, MD). Cyclophosphamide (Sigma) was dissolved in pyrogen-free saline and injected intra-peritoneally (i.p.) at a dose of 200 mg/kg of body weight. Two treatments with cyclophosphamide were performed at day -4 and -2.

DNA Injection

[0138] On day 0, hydrodynamic injection of either a control vector or IL-15 and IL-15Rα expression plasmid into cyclophopshamide treated mice was performed. Empty vector DNA was also administered to the cyclophopshamide-untreated mice, as control. Briefly, 0.2 μg to 2 μg of DNA in 1.6 ml of sterile 0.9% NaCl were injected into mice through the tail vein within 7 seconds using a 27.5 gauge needle. Highly purified, endotoxin-free DNA plasmids were produced using Qiagen EndoFree Giga kit (Qiagen, Hilden).

Lymphocyte analysis

[0139] Mice were sacrificed at different time points (days 2-26) after DNA injection and serum, bone marrow, thymus, spleen, liver and lungs were collected for analysis.

[0140] For bone marrow lymphocyte isolation, left and right femurs were collected and centrifuged at 13,000 for 5 min, re-suspended, and centrifuged again (total of 3 times). Collected cells were re-suspended in RPMI containing 10% fetal calf serum and viable cells were counted using Acridine Orange (Molecular Probes)/Ethidium Bromide (Fisher) dye.

[0141] For splenocyte or thymocyte isolation, spleens or thymi were gently squeezed through a 100 μm Cell Strainer (Thomas) and washed in RPMI (Gibco) to remove any remaining lymphocytes from the organ stroma. After centrifugation, the cells were re-suspended in RPMI containing 10% fetal calf serum and counted.

[0142] To isolate lymphocytes from livers or lungs, the tissues were minced and incubated with 200 U/ml of collagenase (Sigma) and 30 U/ml of DNase (Roche) for 1 h at 37°C, then single cells were collected, centrifuged and re-suspended in complete RPMI with 10% fetal calf serum.

[0143] For phenotyping, the cells were incubated with the following mix of directly conjugated anti-mouse antibodies (BD Pharmingen): CD3-APC, CD4-PerCP, CD8-PECy7, CD44-APC, CD49b-FITC, CD19-PE, CD62L-PE. Labeled cell samples were analyzed by flow cytometry using an LSR II Flow Cytometer (BD) and were analyzed using FlowJo software (Tree Star, San Carlos, CA).

[0144] Lymphocytes of the different group of mice were counted and compared. Statistical analyses were performed using the Prism Software Program. Comparisons of two groups were performed by non-parametric Mann-Whitney t test. Confidence intervals were 0.05, and all p values were two-tailed.

Results

[0145] Two injections of cyclophosphamide at days -4 and -2 were used to generate lymphodepleted mice. At day 0 (and also, for some mice at day 10) IL-15/15Rα DNA expression vector was injected in the tail vein, which generated high systemic levels of bioactive IL-15/15Rα, as published (Bergamaschi, *et al.*, *J Biol Chem.* (2008) 283(7):4189-99). The biological effects after injection of IL-15/15Rα DNA were compared to the injection of a non-producing DNA (vector BV) as negative control in cyclophosphamide-treated animals.

[0146] Different tissues, including lung, liver, spleen, thymus and bone marrow, were extracted from mice sacrificed at days 2-26 from DNA injection and the lymphocyte populations were studied.

[0147] Cyclophosphamide treatment had strong effects on lymphocytes, as reflected in the increased spleen weight of treated animals (Figure 7). Four animals per time point were sacrificed and the spleen weight was monitored. The two groups treated with cyclophosphamide (CP+vector, treated with a non-producing DNA vector; CP+IL-15) had a smaller spleen at day 2 after DNA treatment (4 days after cyclophosphamide). At this early point and also at day 5 the IL-15 treated animals showed a statistically significant difference in spleen size, indicating accelerated recovery by IL-15.

Lung

[0148] We also analyzed lymphocyte numbers and subsets in different tissues to evaluate the effects of IL-15/15Rα administration. These experiments were performed after one or two IL-15/15Rα DNA administrations (at days 0 and 10).

[0149] Lung lymphocytes were evaluated in order to determine the effects of IL-15/15Rα on a peripheral site, where lymphocytes need to function. IL-15 is known to affect strongly CD8+ T cells and NK cells. High levels of IL-15 (achieved with two injections of 2 μg DNA at days 0 and 10), favors lymphocyte recovery in the lung after Cyp treatment.

Effects on Natural Killer (NK) cells:

[0150] Mice were treated at days -4 and -2 and injected with DNA at day 0. Two groups of mice were injected with either BV negative control DNA or with IL-15/IL-15Rα DNA. The IL-15/IL-15Rα-treated animals had a trend for higher NK numbers for all time points. At day 14, comparison of the group receiving empty vector with the group of 2x IL-15/IL-15Rα administration (DNA injections at days 0 and 10) showed that IL-15/15Rα significantly increased lung NK cell recovery ($p=0.03$).

[0151] The lymphocyte population that recovers first is the NK cells. In our experiments after cyclophosphamide treatment the NK cells recovered partially in the absence of any other intervention. IL-15/15Rα administration accelerated this recovery. The best recovery was observed after two IL-15 injections at days 0 and 10. Examination at day 14 showed a significant increase in NK by IL-15 compared to Cyp ($p=0.03$). *See*, Figure 8.

Effects on Lung T cells

[0152] In contrast to NK cells, lung T cells do not recover as fast. The mice were treated and analyzed as above. Lung T cells were enumerated at day 14 after the first DNA injection. It was found that total T cells increased at day 14 after two IL-15/Rα administrations at days 0 and 10, compared to the Cyp treated animals. *See*, Figure 9.

[0153] The lung T cells were also distinguished according to expression of CD4 or CD8 and compared among different groups of mice. It was found that the CD8+ T cells increased preferentially after IL-15/15Rα administration at day 14 (p=0.0357). Moreover, at days 6 and 14 the CD8/CD4 ratio was increased, demonstrating the preferential stimulation of CD8+ T cells by IL-15. The ratio returns to normal by day 26, in the group that received IL-15/15Rα. *See*, Figures 10 and 11.

Spleen

[0154] In the spleen, we also found that T cells recover faster after two injections of IL-15/15Rα (p= 0.0357). Similar to the results in the lung, two doses of IL-15/15Rα (days 0 and 10) were able to increase spleen lymphocytes after Cyp (p=0.03). *See*, Figure 12.

Bone Marrow

[0155] Sustained high level of IL-15 (achieved with two injections of 2 μg DNA at days 0 and 10) resulted in T cell recovery in bone marrow by day 14 after the first DNA injection (Figure 13). IL-15 affected both CD4 and CD8 compartments. Treatment with two administrations of IL-15/15Rα resulted in high levels of bone marrow T cells at day 14 compared to Cyp treated animals.

Example 3: Therapeutic effects of IL-15 on lymphopenia in two different mouse strains

[0156] This example also employed Black6 mice to analyze therapeutic effects of various forms of IL-15 on lymphopenia. Two different mouse strains, BALB/c and Black6, were used in these experiments. Both strains showed accelerated lymphocyte reconstitution upon treatment with IL-15/IL-15Rα.

Treatment of lymphoablated mice with IL-15 DNA

[0157] Female Balb/c or Black6 mice 6-8 weeks in age were treated intra-peritoneally with a dose of 200 mg/kg of body weight of cyclophosphamide (CYP, Figure 14). Two injections of CYP were performed at day -4 and day -2. At day 0 and day 5, hydrodynamic injection of either a control DNA or DNA expressing IL-15/IL-15sRα soluble molecule was performed. Control vector was also delivered in CYP-untreated mice as control. Mice were sacrificed at different time points: day -1 to assess the CYP-induced lymphoablation and day 5, 10, 17 and 24 to follow immune reconstitution in presence or absence of exogenous IL-15. Different tissues (spleen, thymus, bone marrow, lung and liver) were harvested and analyzed for the presence of different lymphocyte subsets. Analysis was performed by flow cytometry after staining the cells with fluorescent-labeled antibodies.

[0158] For flow analysis, isolated cells were incubated with the following directly conjugated anti-mouse antibodies (BD Pharmingen) in appropriate combinations according to the objectives of the experiment:
CD3-APC or CD3-APC-Cy7, CD4-PerCp, CD8-Pacific Blue, CD44-APC, CD62L-PE, CD19-APC-Cy7 or CD19-PeCy7, CD49b-FITC, CD25-APC-Cy7, CD122-PE. T cells were defined as $CD3^+$ cells in the lymphocyte gate; NK cells were defined as $CD3^-CD49b^+$ cells.

[0159] For identification of Treg population (T $CD4^+CD25^+FoxP3^+$ cells), the cells were fixed and permeabilized (eBioscience), and incubated with anti-mouse FoxP3-PeCy7 antibody (eBioscience). T effector cells were defined as $CD3^+FoxP3^-$ lymphocytes. Therefore, the term "Teffector" as used in here refers to all T cells except Treg.

[0160] Figure 15 shows the reconstitution of NK cell compartment in spleen and lung after CYP treatment. CYP-untreated mice were used as baseline control (squares). Two injections of CYP resulted in a drastic reduction of the absolute number of NK cells in both spleen and lung (day -1). NK cells spontaneously recover between day 10 and day 14 days after control DNA injection (triangles). One single administration of IL-15/IL-15sRα DNA was able to promote a full recovery of NK within 5 days after DNA injection. The second IL-15/IL-15sRα expressing DNA injection resulted in an even further expansion of NK cells in both spleen and lung (circles).

[0161] Figure 16 shows the reconstitution of T cell compartment in spleen and lung after CYP treatment. CYP-untreated mice were used as baseline control (squares). Two injections of CYP resulted in a 4 fold reduction in the level of splenic T cells and in 10 fold reduction in the level of T cells residing in the lung (day -1). The spontaneous recovery of T cells appeared to be slower in comparison with the recovery of NK cells and was still incomplete at day 24 after control DNA injection. The kinetics of spontaneous recovery of T CD8 and T CD4 was similar in both spleen and lung (triangles). Two injections of DNA expressing IL-15/IL-15sRα were able to fully reconstitute the T cell numbers within 10 days after DNA administration in both spleen and lung. IL-15 promoted mainly the expansion of T CD8 cells that reached normal level at day 5 after DNA injection and were boosted over normal level at day 10 after DNA injection. IL-15 did not significantly affect the recovery of T CD4 and B cells.

[0162] In addition, T cells recovering in the presence of high level of IL-15/IL-15sRα show increased T effector (Teff)/T regulatory (Treg) ratio and increased ability to secrete IFNgamma and greater degranulation after in vitro stimulation. Figure 17 is an analysis of

the Teff/Treg ratio after CYP treatment for lymphodepletion and during the recovery phase. The Teff/Treg ratio increased significantly at day 10 after IL-15/15sRα DNA injection.

Example 4. DNA delivery for IL-15 to treat lymphopenia

[0163] In these examples, three preferred DNA vector combinations are evaluated for the therapeutic delivery of IL-15 to treat lymphopenia:

1 Co-delivery in the same cells, using preferably optimized expression plasmids expressing IL-15 and essentially full-length IL-15Rα, such as SEQ ID NO:13 and SEQ ID NO:14.

2 Co-delivery in the same cells, using preferably optimized expression plasmids expressing IL-15 and soluble (s) IL-15Rα, such as SEQ ID NO:15.

3 Co-delivery in the same cells, using preferably optimized expression plasmids expressing IL-15 and IL-15Rα fusions to the constant region of an immunoglobulin molecule (Fc) such as SEQ ID NO:16 and SEQ ID NO:19. The construction of Fc fusion proteins is known in the art. Such constructs have been used in *in vivo* experiments in mice to show that IL-15 and IL15Rα-Fc fusion heterodimers are active *in vivo*.

[0164] Delivery of IL-15/IL-15Rα heterodimer by approach (1) above leads to expression of both plasma membrane-bound and secreted IL-15/IL-15Rα. Delivery by approach (2) leads to exclusively secreted IL-15/IL-15Rα heterodimer. Delivery by approach (3) leads to a secreted bioactive heterodimer, which is then bound to cells expressing the Fc Ab receptor on their surface. These cells can present the IL-15/IL-15RαFc heterodimer to neighboring cells, resulting in activation.

[0165] The three types of vectors have been tested in mice and have been shown to produce systemically bioactive levels of IL-15/IL-15Rα (see Figure 18, showing expression of the three types of complexes). Because the localization, trafficking and stability of the different types of complexes vary, the biological effects on lymphocytes is also variable. Figure 18 shows expression of different IL-15/IL-15Rα heterodimeric forms in mice by hydrodynamic injection of DNA vectors. Mice were injected at the tail vein (hydrodynamic delivery) with 0.1 μg of DNA expressing the different forms of IL-15/IL-15Rα. Plasma levels of IL-15 were measured at days 1 and 2.5 by R&D Quantiglo ELISA. Measurement of plasma levels of IL-15 produced by the different vectors showed that the highest plasma levels were achieved by the DNA vector producing IL-15/IL-15RαFc fusion. The stability of the produced proteins was also different, with the IL-15/IL-15RαFc and the IL-15/IL-15Rα full

length showing the greatest stability. The IL-15/sIL-15Rα that is not cell associated was less stable.

[0166] Table 2 shows the CD4/CD8 ratios measured in the spleen and lung of mice treated with different IL-15/IL-15Rα heterodimeric forms, 2 ½ days after hydrodynamic injection of 0.1 μg of DNA vector (see Figure 17).

VECTOR	Spleen	Lung
IL-15/IL-15Rα (full length)	1.36	0.8
IL-15/sIL-15Rα (soluble)	0.81	0.24
IL-15/IL-15RαFc fusion to Fc	0.63	0.52
DNA vector control	2	1.61

[0167] In these experiments, it was discovered that the different molecules have differential effects on lymphocytes. Therefore, the different IL-15 complexes can be used alone or in combinations for the most beneficial treatment under specific conditions. For example, delivery of combinations of IL-15/sRα soluble complex and IL-15/15RαFc fusion complex provides the opportunity to deliver both soluble and cell-bound IL-15 (through the Fc receptor) at different levels and proportions.

[0168] In addition to the different ratios of CD4/CD8 cells (as shown in Table 1), the different IL-15 heterodimers also showed differences in the effects on other surface markers of lymphocytes. Figure 19 shows that IL-15/15RαFc expression induced high levels of CD25 (IL-2 Receptor alpha) on both T CD4 and T CD8 cells, whereas the other forms of IL-15/IL-15Rα heterodimers did not affect CD25 expression strongly.

[0169] Figure 20 shows that IL-15/IL-15RαFc increased the levels of CD62L on the surface of spleen T cells, whereas the other forms of IL-15/IL-15Rα either did not affect or decreased average levels of CD62L on spleen T cells. In contrast, IL-15/IL-15RαFc was less effective in increasing CD44 on spleen T cells compared to either IL-15/IL-15Rα full-length or IL-15/IL-15sRα (Figure 21).

Example 5. Protein Delivery

[0170] As an alternative method to provide IL-15, delivery of purified protein can be used. Protein purification from cell lines over-producing IL-15/IL-15Rα complexes has been achieved. Similar to DNA, different forms of the heterodimer can be used alone or in combinations for obtaining the appropriate effects:

1 Delivery of purified IL-15/soluble (s) IL-15Rα, such as SEQ ID NO:10 and SEQ ID NO:12.

2 Delivery of purified IL-15/IL-15RαFc fusion protein (fusion to the constant region of an immunoglobulin molecule, such as SEQ ID NO:17 and SEQ ID NO:20)

[0171] IL-15/sIL-15Rα was purified from overproducing human 293 cells and delivered into lympho-ablated mice. The results showed that this heterodimer is bioactive and that it promoted the proliferation of adoptively transferred lymphocytes (T cells, NK cells, but not B cells).

[0172] Experimental procedure (Figure 22): Mice were treated with Cyclophosphamide (Cyp) and two days later they were given 3 μg of HPLC-purified IL-15/s15Ra protein intraperitoneally for 6 days. Splenocytes were purified from young Bl/6 mice, labeled with CFSE, and 10^7 cells were injected by the IV route to the lympho-ablated animals. Proliferation of the adoptively transferred cells was followed by CFSE dilution.

[0173] Thus, these results indicate that different forms of IL-15/IL-15Rα heterodimer have different stability, interactions in the body, processing and stability. This offers the opportunity to exploit such properties for using these cytokines to provide maximal benefit. Accordingly, the different forms can be combined in different ratios and administration schedules. Different forms can be administered either simultaneously or sequentially.

[0174] IL-15Rα – Fc fusions previously employed have been used with various degrees of effectiveness. The studies exemplified in Figure23 show that the Fc fusion we used has greater plasma half-life compared to IL-15/s15Rα.

[0175] In the examples of sequences, described herein, the 205FC fusion (SEQ ID NO:17) contains the natural processing site generating the s15Rα from the membrane-bound form, whereas the 200FC fusion (SEQ ID NO:20) does not have an intact processing site. These are examples of Fc fusions that may be processed differently to generate non-cell associated forms after cleavage between the 15Rα region and the antibody constant region. Additional molecules can be generated having processing sites for cleavage and generating both cell associated and soluble forms of the cytokine. Additional methods for cell attachment, other than the Fc region are known in the art and can also be employed.

It is understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be

suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims. All publications, patents, and patent applications cited herein are hereby incorporated by reference in their entirety for all purposes.

EXAMPLES OF SEQUENCES

SEQ ID NO:1
Human wild-type IL-15 nucleic acid sequence

ATGAGAATTTCGAAACCACATTTGAGAAGTATTTCCATCCAGTGCTACTTGTGTTTACTTCT
AAACAGTCATTTTCTAACTGAAGCTGGCATTCATGTCTTCATTTTGGGCTGTTTCAGTGCAG
GGCTTCCTAAAACAGAAGCCAACTGGGTGAATGTAATAAGTGATTTGAAAAAAATTGAAGAT
CTTATTCAATCTATGCATATTGATGCTACTTTATATACGGAAAGTGATGTTCACCCCAGTTG
CAAAGTAACAGCAATGAAGTGCTTTCTCTTGGAGTTACAAGTTATTTCACTTGAGTCTGGAG
ATGCAAGTATTCATGATACAGTAGAAAATCTGATCATCCTAGCAAACAACAGTTTGTCTTCT
AATGGGAATGTAACAGAATCTGGATGCAAAGAATGTGAGGAACTGGAGGAAAAAAATATTAA
AGAATTTTTGCAGAGTTTTGTACATATTGTCCAAATGTTCATCAACACTTCTTGA

SEQ ID NO:2
Human wild-type IL-15 amino acid sequence

M	R	I	S	K	P	H	L	R	S	I	S	I	Q	C	Y	L	C	L	L	L
N	S	H	F	L	T	E	A	G	I	H	V	F	I	L	G	C	F	S	A	G
L	P	K	T	E	A	N	W	V	N	V	I	S	D	L	K	K	I	E	D	L
I	Q	S	M	H	I	D	A	T	L	Y	T	E	S	D	V	H	P	S	C	K
V	T	A	M	K	C	F	L	L	E	L	Q	V	I	S	L	E	S	G	D	A
S	I	H	D	T	V	E	N	L	I	I	L	A	N	N	S	L	S	S	N	G
N	V	T	E	S	G	C	K	E	C	E	E	L	E	E	K	N	I	K	E	F
L	Q	S	F	V	H	I	V	Q	M	F	I	N	T	S	•					

SEQ ID NO:3
Human improved IL-15 nucleic acid sequence (opt1)

ATGCGGATCTCGAAGCCGCACCTGCGGTCGATATCGATCCAGTGCTACCTGTGCCTGCTCCT
GAACTCGCACTTCCTCACGGAGGCCGGTATACACGTCTTCATCCTGGGCTGCTTCTCGGCGG
GGCTGCCGAAGACGGAGGCGAACTGGGTGAACGTGATCTCGGACCTGAAGAAGATCGAGGAC
CTCATCCAGTCGATGCACATCGACGCGACGCTGTACACGGAGTCGGACGTCCACCCGTCGTG
CAAGGTCACGGCGATGAAGTGCTTCCTCCTGGAGCTCCAAGTCATCTCGCTCGAGTCGGGGG
ACGCGTCGATCCACGACACGGTGGAGAACCTGATCATCCTGGCGAACAACTCGCTGTCGTCG
AACGGGAACGTCACGGAGTCGGGCTGCAAGGAGTGCGAGGAGCTGGAGGAGAAGAACATCAA
GGAGTTCCTGCAGTCGTTCGTGCACATCGTCCAGATGTTCATCAACACGTCGTGA

SEQ ID NO:4
Human improved IL-15 nucleic acid sequence (opt2)

ATGAGGATCAGCAAGCCCCACCTGAGGAGCATCAGCATCCAGTGCTACCTGTGCCTGCTGCT
GAACAGCCACTTCCTGACCGAGGCCGGTATACACGTGTTCATCCTGGGCTGCTTTAGCGCCG
GACTGCCCAAGACCGAGGCCAATTGGGTGAACGTGATCAGCGACCTGAAGAAGATCGAGGAC

CTCATCCAGAGCATGCACATCGACGCCACCCTGTACACCGAGAGCGATGTGCACCCCAGCTG
TAAGGTGACCGCCATGAAGTGCTTTCTGCTGGAGCTGCAAGTGATCAGCCTGGAGAGCGGCG
ACGCCAGCATCCACGACACCGTGGAGAACCTGATCATCCTGGCCAACAACAGCCTGAGCAGC
AACGGCAATGTGACCGAGAGCGGCTGTAAGGAGTGTGAGGAGCTGGAGGAGAAGAACATCAA
GGAGTTTCTGCAGAGCTTCGTGCACATCGTGCAGATGTTCATCAACACCAGCTGA

SEQ ID NO:5
Homo sapiens interleukin 15 receptor, alpha (IL15RA), transcript variant 1, mRNA - GenBank Accession No. NM_002189

```
   1 cccagagcag cgctcgccac ctccccccgg cctgggcagc gctcgcccgg ggagtccagc
  61 ggtgtcctgt ggagctgccg ccatggcccc gcggcgggcg cgcggctgcc ggaccctcgg
 121 tctcccggcg ctgctactgc tgctgctgct ccggccgccg gcgacgcggg gcatcacgtg
 181 ccctcccccc atgtccgtgg aacacgcaga catctgggtc aagagctaca gcttgtactc
 241 cagggagcgg tacatttgta actctggttt caagcgtaaa gccggcacgt ccagcctgac
 301 ggagtgcgtg ttgaacaagg ccacgaatgt cgcccactgg acaaccccca gtctcaaatg
 361 cattagagac cctgccctgg ttcaccaaag gccagcgcca ccctccacag taacgacggc
 421 aggggtgacc ccacagccag agagcctctc cccttctgga aaagagcccg cagcttcatc
 481 tcccagctca aacaacacag cggccacaac agcagctatt gtcccgggct cccagctgat
 541 gccttcaaaa tcaccttcca caggaaccac agagataagc agtcatgagt cctcccacgg
 601 caccccctct cagacaacag ccaagaactg ggaactcaca gcatccgcct cccaccagcc
 661 gccaggtgtg tatccacagg gccacagcga caccactgtg gctatctcca cgtccactgt
 721 cctgctgtgt gggctgagcg ctgtgtctct cctggcatgc tacctcaagt caaggcaaac
 781 tcccccgctg gccagcgttg aaatggaagc catggaggct ctgccggtga cttgggggac
 841 cagcagcaga gatgaagact tggaaaactg ctctcaccac ctatgaaact cggggaaacc
 901 agcccagcta agtccggagt gaaggagcct ctctgcttta gctaaagacg actgagaaga
 961 ggtgcaagga agcgggctcc aggagcaagc tcaccaggcc tctcagaagt cccagcagga
1021 tctcacggac tgccgggtcg gcgcctcctg cgcgagggag caggttctcc gcattcccat
1081 gggcaccacc tgcctgcctg tcgtgccttg gacccagggc ccagcttccc aggagagacc
1141 aaaggcttct gagcaggatt tttatttcat tacagtgtga gctgcctgga atacatgtgg
1201 taatgaaata aaaaccctgc cccgaatctt ccgtccctca tcctaacttt cagttcacag
1261 agaaaagtga catacccaaa gctctctgtc aattacaagg cttctcctgg cgtgggagac
1321 gtctacaggg aagacaccag cgtttgggct tctaaccacc ctgtctccag ctgctctgca
1381 cacatggaca gggacctggg aaaggtggga gagatgctga gcccagcgaa tcctctccat
1441 tgaaggattc aggaagaaga aaactcaact cagtgccatt ttacgaatat atgcgtttat
1501 atttatactt ccttgtctat tatatctata cattatatat tatttgtatt ttgacattgt
1561 accttgtata aacaaaataa aacatctatt ttcaatattt ttaaaatgca
```

SEQ ID NO:6
interleukin 15 receptor, alpha isoform 1 precursor [Homo sapiens] - GenBank Accession No. NP_002180

```
   1 maprrargcr tlglpallll lllrppatrg itcpppmsve hadiwvksys lysreryicn
  61 sgfkrkagts sltecvlnka tnvahwttps lkcirdpalv hqrpappstv ttagvtpqpe
 121 slspsgkepa asspssnnta attaaivpgs qlmpskspst gtteisshes shgtpsqtta
 181 knweltasas hqppgvypqg hsdttvaist stvllcglsa vsllacylks rqtpplasve
 241 meamealpvt wgtssrdedl encshhl
```

SEQ ID NO:7

Homo sapiens interleukin 15 receptor, alpha (IL15RA), transcript variant 2, mRNA - GenBank Accession No. NM_172200

```
   1 caggaattcg gcgaagtggc ggagctgggg ccccagcggg cgccgggggc cgcgggagcc
  61 agcaggtggc gggggctgcg ctccgcccgg gccagagcgc accaggcagg tgcccgcgcc
 121 tccgcaccgc ggcgacacct ccgcgggcac tcacccaggc cggccgctca caaccgagcg
 181 cagggccgcg gagggagacc aggaaagccg aaggcggagc agctggaggc gaccagcgcc
 241 gggcgaggtc aagtggatcc gagccgcaga gagggctgga gagagtctgc tctccgatga
 301 ctttgcccac tctcttcgca gtggggacac cggaccgagt gcacactgga ggtcccagag
 361 cacgacgagc gcggaggacc gggaggctcc cgggcttgcg tgggcatcac gtgccctccc
 421 cccatgtccg tggaacacgc agacatctgg gtcaagagct acagcttgta ctccagggag
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 481 cggtacattt gtaactctgg tttcaagcgt aaagccggca cgtccagcct gacggagtgc
 541 gtgttgaaca aggccacgaa tgtcgcccac tggacaaccc ccagtctcaa atgcattaga
 601 gaccctgccc tggttcacca aaggccagcg ccaccctcca cagtaacgac ggcaggggtg
 661 accccacagc cagagagcct ctccccttct ggaaaagagc ccgcagcttc atctcccagc
 721 tcaaacaaca cagcggccac aacagcagct attgtcccgg gctcccagct gatgccttca
 781 aaatcacctt ccacaggaac cacagagata agcagtcatg agtcctccca cggcaccccc
 841 tctcagacaa cagccaagaa ctgggaactc acagcatccg cctcccacca gccgccaggt
 901 gtgtatccac agggccacag cgacaccact gtggctatct ccacgtccac tgtcctgctg
 961 tgtgggctga gcgctgtgtc tctcctggca tgctacctca agtcaaggca aactcccccg
1021 ctggccagcg ttgaaatgga agccatggag gctctgccgg tgacttgggg gaccagcagc
1081 agagatgaag acttggaaaa ctgctctcac cacctatgaa actcggggaa accagcccag
1141 ctaagtccgg agtgaaggag cctctctgct ttagctaaag acgactgaga agaggtgcaa
1201 ggaagcgggc tccaggagca agctcaccag gcctctcaga agtcccagca ggatctcacg
1261 gactgccggg tcggcgcctc ctgcgcgagg gagcaggttc tccgcattcc catgggcacc
1321 acctgcctgc ctgtcgtgcc ttggacccag ggcccagctt cccaggagag accaaaggct
1381 tctgagcagg atttttattt cattacagtg tgagctgcct ggaatacatg tggtaatgaa
1441 ataaaaaccc tgccccgaat cttccgtccc tcatcctaac tttcagttca cagagaaaag
1501 tgacataccc aaagctctct gtcaattaca aggcttctcc tggcgtggga gacgtctaca
1561 gggaagacac cagcgtttgg gcttctaacc accctgtctc cagctgctct gcacacatgg
1621 acagggacct gggaaaggtg ggagagatgc tgagcccagc gaatcctctc cattgaagga
1681 ttcaggaaga agaaaactca actcagtgcc attttacgaa tatatgcgtt tatatttata
1741 cttccttgtc tattatatct atacattata tattatttgt attttgacat tgtaccttgt
1801 ataaacaaaa taaaacatct attttcaata tttttaaaat gca
```

SEQ ID NO:8

interleukin 15 receptor, alpha isoform 2 [Homo sapiens] - GenBank Accession No. NP_751950

```
   1 msvehadiwv ksyslysrer yicnsgfkrk agtssltecv lnkatnvahw ttpslkcird
  61 palvhqrpap pstvttagvt pqpeslspsg kepaasspss nntaattaai vpgsqlmpsk
 121 spstgtteis shesshgtps qttaknwelt asashqppgv ypqghsdttv aiststvllc
 181 glsavsllac ylksrqtppl asvemeamea lpvtwgtssr dedlencshh l
```

SEQ ID NO:9

Improved human interleukin 15 (IL-15) receptor alpha (IL15Ra), transcript variant 1 (OPT)

```
atggccccga ggcgggcgcg aggctgccgg accctcggtc tcccggcgct gctactgctc 60
ctgctgctcc ggccgccggc gacgcggggc atcacgtgcc cgccccccat gtccgtggag 120
cacgcagaca tctgggtcaa gagctacagc ttgtactccc gggagcggta catctgcaac 180
tcgggtttca agcggaaggc cggcacgtcc agcctgacgg agtgcgtgtt gaacaaggcc 240
acgaatgtcg cccactggac gacccccctcg ctcaagtgca tccgcgaccc ggccctggtt 300
caccagcggc ccgcgccacc ctccaccgta acgacggcgg gggtgacccc gcagccggag 360
agcctctccc cgtcgggaaa ggagcccgcc gcgtcgtcgc ccagctcgaa caacacggcg 420
gccacaactg cagcgatcgt cccgggctcc cagctgatgc cgtcgaagtc gccgtccacg 480
ggaaccacgg agatcagcag tcatgagtcc tcccacggca ccccctcgca aacgacggcc 540
aagaactggg aactcacggc gtccgcctcc caccagccgc cgggggtgta tccgcaaggc 600
cacagcgaca ccacggtggc gatctccacg tccacggtcc tgctgtgtgg gctgagcgcg 660
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atggaggcca tggaggctct gccggtgacg tgggggacca gcagcaggga tgaggacttg 780
gagaactgct cgcaccacct ataatga                                     807
```

SEQ ID NO:10 - improved human interleukin 15 (IL-15) receptor alpha (IL15Ra), transcript variant 1 (OPT)

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Met Ala Pro Arg Arg Ala Arg Gly Cys Arg Thr Leu Gly Leu Pro Ala
  1               5                  10                  15
Leu Leu Leu Leu Leu Leu Leu Arg Pro Pro Ala Thr Arg Gly Ile Thr
             20                  25                  30
```

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Cys Pro Pro Pro Met Ser Val Glu His Ala Asp Ile Trp Val Lys Ser
         35                  40                  45
Tyr Ser Leu Tyr Ser Arg Glu Arg Tyr Ile Cys Asn Ser Gly Phe Lys
     50                  55                  60
Arg Lys Ala Gly Thr Ser Ser Leu Thr Glu Cys Val Leu Asn Lys Ala
 65                  70                  75                  80
Thr Asn Val Ala His Trp Thr Thr Pro Ser Leu Lys Cys Ile Arg Asp
                 85                  90                  95
Pro Ala Leu Val His Gln Arg Pro Ala Pro Pro Ser Thr Val Thr Thr
            100                 105                 110
Ala Gly Val Thr Pro Gln Pro Glu Ser Leu Ser Pro Ser Gly Lys Glu
        115                 120                 125
Pro Ala Ala Ser Ser Pro Ser Ser Asn Asn Thr Ala Ala Thr Thr Ala
    130                 135                 140
Ala Ile Val Pro Gly Ser Gln Leu Met Pro Ser Lys Ser Pro Ser Thr
145                 150                 155                 160
Gly Thr Thr Glu Ile Ser Ser His Glu Ser Ser His Gly Thr Pro Ser
                165                 170                 175
Gln Thr Thr Ala Lys Asn Trp Glu Leu Thr Ala Ser Ala Ser His Gln
            180                 185                 190
Pro Pro Gly Val Tyr Pro Gln Gly His Ser Asp Thr Thr Val Ala Ile
        195                 200                 205
Ser Thr Ser Thr Val Leu Leu Cys Gly Leu Ser Ala Val Ser Leu Leu
    210                 215                 220
Ala Cys Tyr Leu Lys Ser Arg Gln Thr Pro Pro Leu Ala Ser Val Glu
225                 230                 235                 240
Met Glu Ala Met Glu Ala Leu Pro Val Thr Trp Gly Thr Ser Ser Arg
                245                 250                 255
Asp Glu Asp Leu Glu Asn Cys Ser His His Leu
            260                 265
```

SEQ ID NO:11 - improved human soluble interleukin 15 (IL-15) receptor alpha (IL-15sRa) (OPT)

```
atggccccga ggcgggcgcg aggctgccgg accctcggtc tcccggcgct gctactgctc 60
ctgctgctcc ggccgccggc gacgcggggc atcacgtgcc cgccccccat gtccgtggag 120
cacgcagaca tctgggtcaa gagctacagc ttgtactccc gggagcggta catctgcaac 180
tcgggtttca agcggaaggc cggcacgtcc agcctgacgg agtgcgtgtt gaacaaggcc 240
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caccagcggc ccgcgccacc ctccaccgta acgacggcgg gggtgacccc gcagccggag 360
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gccacaactg cagcgatcgt cccgggctcc cagctgatgc cgtcgaagtc gccgtccacg 480
ggaaccacgg agatcagcag tcatgagtcc tcccacggca ccccctcgca aacgacggcc 540
aagaactggg aactcacggc gtccgcctcc caccagccgc cgggggtgta tccgcaaggc 600
cacagcgaca ccacgtaatg a                                           621
```

SEQ ID NO:12 - improved human soluble interleukin 15 (IL-15) receptor alpha (IL-15sRa) (OPT)

```
Met Ala Pro Arg Arg Ala Arg Gly Cys Arg Thr Leu Gly Leu Pro Ala
  1               5                  10                  15
Leu Leu Leu Leu Leu Leu Leu Arg Pro Pro Ala Thr Arg Gly Ile Thr
             20                  25                  30
Cys Pro Pro Pro Met Ser Val Glu His Ala Asp Ile Trp Val Lys Ser
         35                  40                  45
Tyr Ser Leu Tyr Ser Arg Glu Arg Tyr Ile Cys Asn Ser Gly Phe Lys
     50                  55                  60
Arg Lys Ala Gly Thr Ser Ser Leu Thr Glu Cys Val Leu Asn Lys Ala
 65                  70                  75                  80
Thr Asn Val Ala His Trp Thr Thr Pro Ser Leu Lys Cys Ile Arg Asp
                 85                  90                  95
Pro Ala Leu Val His Gln Arg Pro Ala Pro Pro Ser Thr Val Thr Thr
            100                 105                 110
Ala Gly Val Thr Pro Gln Pro Glu Ser Leu Ser Pro Ser Gly Lys Glu
        115                 120                 125
Pro Ala Ala Ser Ser Pro Ser Ser Asn Asn Thr Ala Ala Thr Thr Ala
    130                 135                 140
Ala Ile Val Pro Gly Ser Gln Leu Met Pro Ser Lys Ser Pro Ser Thr
145                 150                 155                 160
Gly Thr Thr Glu Ile Ser Ser His Glu Ser Ser His Gly Thr Pro Ser
                165                 170                 175
Gln Thr Thr Ala Lys Asn Trp Glu Leu Thr Ala Ser Ala Ser His Gln
            180                 185                 190
Pro Pro Gly Val Tyr Pro Gln Gly His Ser Asp Thr Thr
        195                 200                 205
```

SEQ ID NO:13
Dual expression plasmid human IL15Ra+IL15

CCTGGCCATTGCATACGTTGTATCCATATCATAATATGTACATTTATATTGGCTCATGTCCA
ACATTACCGCCATGTTGACATTGATTATTGACTAGTTATTAATAGTAATCAATTACGGGGTC
ATTAGTTCATAGCCCATATATGGAGTTCCGCGTTACATAACTTACGGTAAATGGCCCGCCTG
GCTGACCGCCCAACGACCCCCGCCCATTGACGTCAATAATGACGTATGTTCCCATAGTAACG
CCAATAGGGACTTTCCATTGACGTCAATGGGTGGAGTATTTACGGTAAACTGCCCACTTGGC
AGTACATCAAGTGTATCATATGCCAAGTACGCCCCCTATTGACGTCAATGACGGTAAATGGC
CCGCCTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTACATCTAC
GTATTAGTCATCGCTATTACCATGGTGATGCGGTTTTGGCAGTACATCAATGGGCGTGGATA
GCGGTTTGACTCACGGGGATTTCCAAGTCTCCACCCCATTGACGTCAATGGGAGTTTGTTTT
GGCACCAAAATCAACGGGACTTTCCAAAATGTCGTAACAACTCCGCCCCATTGACGCAAATG
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CGCCTGGAGACGCCATCCACGCTGTTTTGACCTCCATAGAAGACACCGGGACCGATCCAGCC
TCCGCGGGCGCGCGTCGAGGAATTCGCTAGCAAGAA**ATGGCCCCGAGGCGGGCGCGAGGCTG**

CCGGACCCTCGGTCTCCCGGCGCTGCTACTGCTCCTGCTGCTCCGGCCGCCGGCGACGCGGG
GCATCACGTGCCCGCCCCCCATGTCCGTGGAGCACGCAGACATCTGGGTCAAGAGCTACAGC
TTGTACTCCCGGGAGCGGTACATCTGCAACTCGGGTTTCAAGCGGAAGGCCGGCACGTCCAG
CCTGACGGAGTGCGTGTTGAACAAGGCCACGAATGTCGCCCACTGGACGACCCCCTCGCTCA
AGTGCATCCGCGACCCGGCCCTGGTTCACCAGCGGCCCGCGCCACCCTCCACCGTAACGACG
GCGGGGGTGACCCCGCAGCCGGAGAGCCTCTCCCCGTCGGGAAAGGAGCCCGCCGCGTCGTC
GCCCAGCTCGAACAACACGGCGGCCACAACTGCAGCGATCGTCCCGGGCTCCCAGCTGATGC
CGTCGAAGTCGCCGTCCACGGGAACCACGGAGATCAGCAGTCATGAGTCCTCCCACGGCACC
CCCTCGCAAACGACGGCCAAGAACTGGGAACTCACGGCGTCCGCCTCCCACCAGCCGCCGGG
GGTGTATCCGCAAGGCCACAGCGACACCACGGTGGCGATCTCCACGTCCACGGTCCTGCTGT
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CCAAACCAAACCTAGCCTCCAAGAGTGGGAAGAAATTAAAGCAAGATAGGCTATTAAGTGCA
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CTCAAAGGCGGTAATACGGTTATCCACAGAATCAGGGGATAACGCAGGAAAGAACATGTGAG
CAAAAGGCCAGCAAAAGGCCAGGAACCGTAAAAAGGCCGCGTTGCTGGCGTTTTTCCATAGG
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CCCTGCCGCTTACCGGATACCTGTCCGCCTTTCTCCCTTCGGGAAGCGTGGCGCTTTCTCAA
TGCTCACGCTGTAGGTATCTCAGTTCGGTGTAGGTCGTTCGCTCCAAGCTGGGCTGTGTGCA
CGAACCCCCCGTTCAGCCCGACCGCTGCGCCTTATCCGGTAACTATCGTCTTGAGTCCAACC
CGGTAAGACACGACTTATCGCCACTGGCAGCAGCCACTGGTAACAGGATTAGCAGAGCGAGG
TATGTAGGCGGTGCTACAGAGTTCTTGAAGTGGTGGCCTAACTACGGCTACACTAGAAGGAC
AGTATTTGGTATCTGCGCTCTGCTGAAGCCAGTTACCTTCGGAAAAAGAGTTGGTAGCTCTT
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SEQ ID NO:14
Dual expression plasmid human IL15Ra+IL15tPA6

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SEQ ID NO:16--DPhuIL15sRa205FC+huGMIL15 The capitalized, bolded region is the coding region for the IL-15Receptor alpha 205FC fusion

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SEQ ID NO:17--huIL15sRa205-Fc—underlined region is IL15sRa sequence

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SEQ ID NO:18--huGMCSF-IL15

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Y T E S D V H P S C K V T A M K C F L L E
L Q V I S L E S G D A S I H D T V E N L I
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F I N T S

SEQ ID NO:19--AG256DPhuIL15sRa200FC+huGMIL15– The capitalized, bolded region is the coding region for the IL-15Receptor alpha 200FC fusion

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R	W	Q	Q	G	N	V	F	S	C	S	V	M	H	E	A	L	H	N	H	Y
T	Q	K	S	L	S	L	S	P	G	K										

WHAT IS CLAIMED IS:

1. A method of promoting T-cell maturation in thymic tissue comprising contacting the thymic tissue with IL-15.

2. The method of claim 1, wherein the thymic tissue is *in vivo*.

3. The method of claim 2, wherein the IL-15 is administered systemically.

4. The method of claim 2, wherein the IL-15 is administered locally.

5. The method of claim 1, wherein the thymic tissue is *in vitro*.

6. The method of claim 1, wherein the IL-15 is delivered as a heterodimer with IL-15Rα.

7. The method of claim 6, wherein the IL-15Rα is a soluble IL-15-Rα that lacks the transmembrane anchor portion and is fused to an Fc region.

8. The method of claim 1, wherein the IL-15 is delivered as a polypeptide.

9. The method of claim 1, wherein the IL-15 is expressed from a polynucleotide encoding IL-15.

10. The method of claim 9, wherein the IL-15 is co-expressed from a single vector with a polynucleotide encoding IL-15Rα.

11. The method of claim 9, wherein the IL-15 is co-expressed from separate vectors with a polynucleotide encoding IL-15Rα.

12. The method of claim 1, wherein the IL-15 has a native signal peptide.

13. The method of claim 1, wherein the IL-15 has a heterologous signal peptide.

14. A method of promoting the migration of lymphocytes from a central lymphoid tissue to one or more peripheral tissues in a subject in need thereof comprising administering to the subject IL-15.

15. The method of claim 14, wherein the central lymphoid tissue is thymus.

16. The method of claim 14, wherein the lymphocytes are T cells.

17. The method of claim 14, wherein the peripheral tissue is a peripheral lymphoid tissue.

18. The method of claim 14, wherein the peripheral tissue is a non-lymphoid tissue.

19. The method of claim 14, wherein the IL-15 is administered systemically.

20. The method of claim 14, wherein the IL-15 is administered locally.

21. The method of claim 14, wherein the IL-15 is delivered as a heterodimer with IL-15Rα.

22. The method of claim 14, wherein the IL-15Rα is a soluble IL-15-Rα that lacks the transmembrane anchor portion and is fused to an Fc region.

23. The method of claim 14, wherein the IL-15 is delivered as a polypeptide.

24. The method of claim 14, wherein the IL-15 is expressed from a polynucleotide encoding IL-15.

25. The method of claim 24, wherein the IL-15 is co-expressed from a single vector with a polynucleotide encoding IL-15Rα.

26. The method of claim 24, wherein the IL-15 is co-expressed from separate vectors with a polynucleotide encoding IL-15Rα.

27. The method of claim 14, wherein the IL-15 has a native signal peptide.

28. The method of claim 14, wherein the IL-15 has a heterologous signal peptide.

29. A method of preventing or reducing lymphopenia in an individual in need thereof comprising systemically administering IL-15 to the individual.

30. The method of claim 29, wherein the IL-15 is delivered as a heterodimer with IL-15Rα.

31. The method of claim 30, wherein the IL-15Rα is a soluble IL-15-Rα that lacks the transmembrane anchor portion and is fused to an Fc region.

32. The method of claim 29, wherein the IL-15 is delivered as a polypeptide.

33. The method of claim 29, wherein the IL-15 is expressed from a polynucleotide encoding IL-15.

34. The method of claim 33, wherein the IL-15 is co-expressed from a single vector with a polynucleotide encoding IL-15Rα.

35. The method of claim 33, wherein the IL-15 is co-expressed from separate vectors with a polynucleotide encoding IL-15Rα.

36. The method of claim 29, wherein the IL-15 has a native signal peptide.

37. The method of claim 29, wherein the IL-15 has a heterologous signal peptide.

38. The method of claim 29, wherein the lymphopenia is drug-induced lymphopenia.

39. The method of claim 29, wherein the individual is receiving anticancer drugs that induce lymphopenia.

40. The method of claim 39, wherein the IL-15 is co-administered with the anticancer agent.

41. A method of promoting the repopulation of lymphocytes in peripheral tissues in an individual in need thereof comprising systemically administering IL-15 to the individual.

42. The method of claim 41, wherein the IL-15 is delivered as a heterodimer with IL-15Rα.

43. The method of claim 41, wherein the IL-15 is delivered as a polypeptide.

44. The method of claim 41, wherein the IL-15 is expressed from a polynucleotide encoding IL-15.

45. The method of claim 44, wherein the IL-15 is co-expressed from a single vector with a polynucleotide encoding IL-15Rα.

46. The method of claim 44, wherein the IL-15 is co-expressed from separate vectors with a polynucleotide encoding IL-15Rα.

47. The method of claim 41, wherein the IL-15 has a native signal peptide.

48. The method of claim 41, wherein the IL-15 has a heterologous signal peptide.

49. The method of claim 41, wherein the peripheral tissue is a peripheral lymphoid tissue.

50. The method of claim 41, wherein the peripheral tissue is a non-lymphoid tissue.

Figure 1

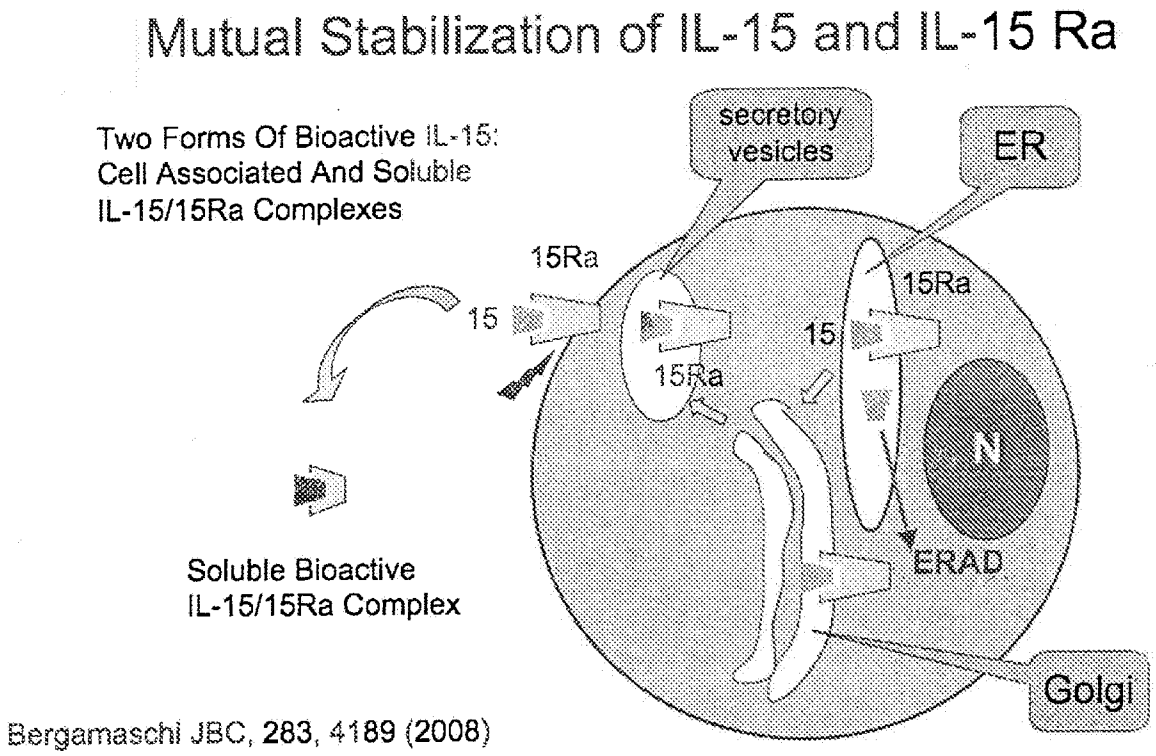
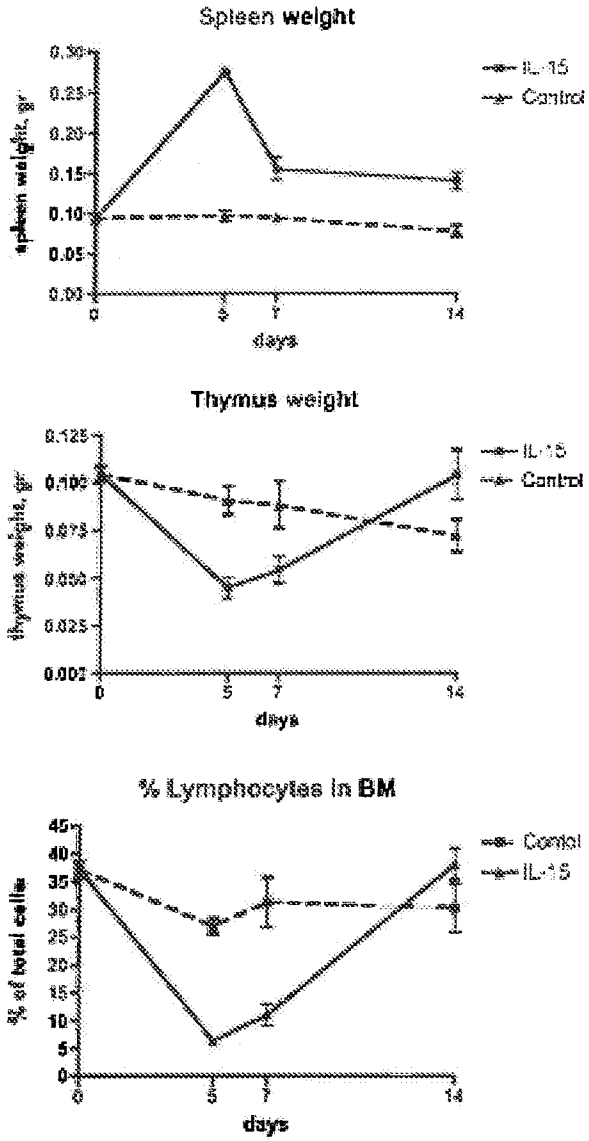
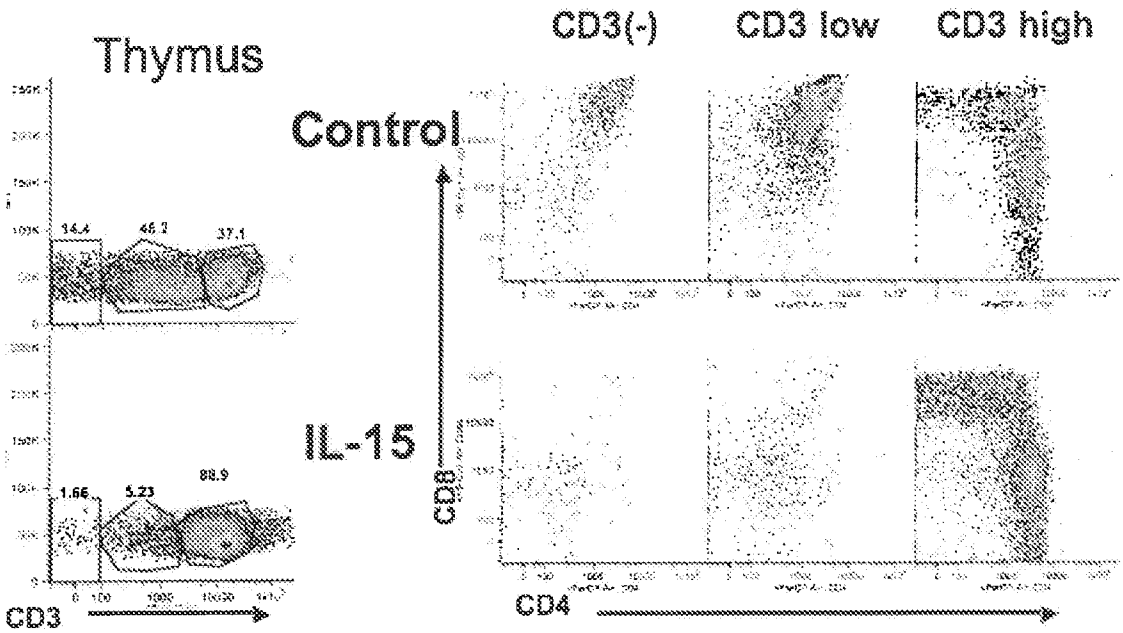

Mutual Stabilization of IL-15 and IL-15 Ra
Two Forms Of Bioactive IL-15:
Cell Associated And Soluble
IL-15/15Ra Complexes
secretory vesicles
ER
15Ra
15
15Ra
15
15Ra
N
ERAD
Golgi
Soluble Bioactive
IL-15/15Ra Complex
Bergamaschi JBC, 283, 4189 (2008)

Figure 2



IL-15 effects on spleen, thymus, BM

Figure 3



Effects of IL-15 on the thymus. Double positive cells are eliminated.

Figure 4

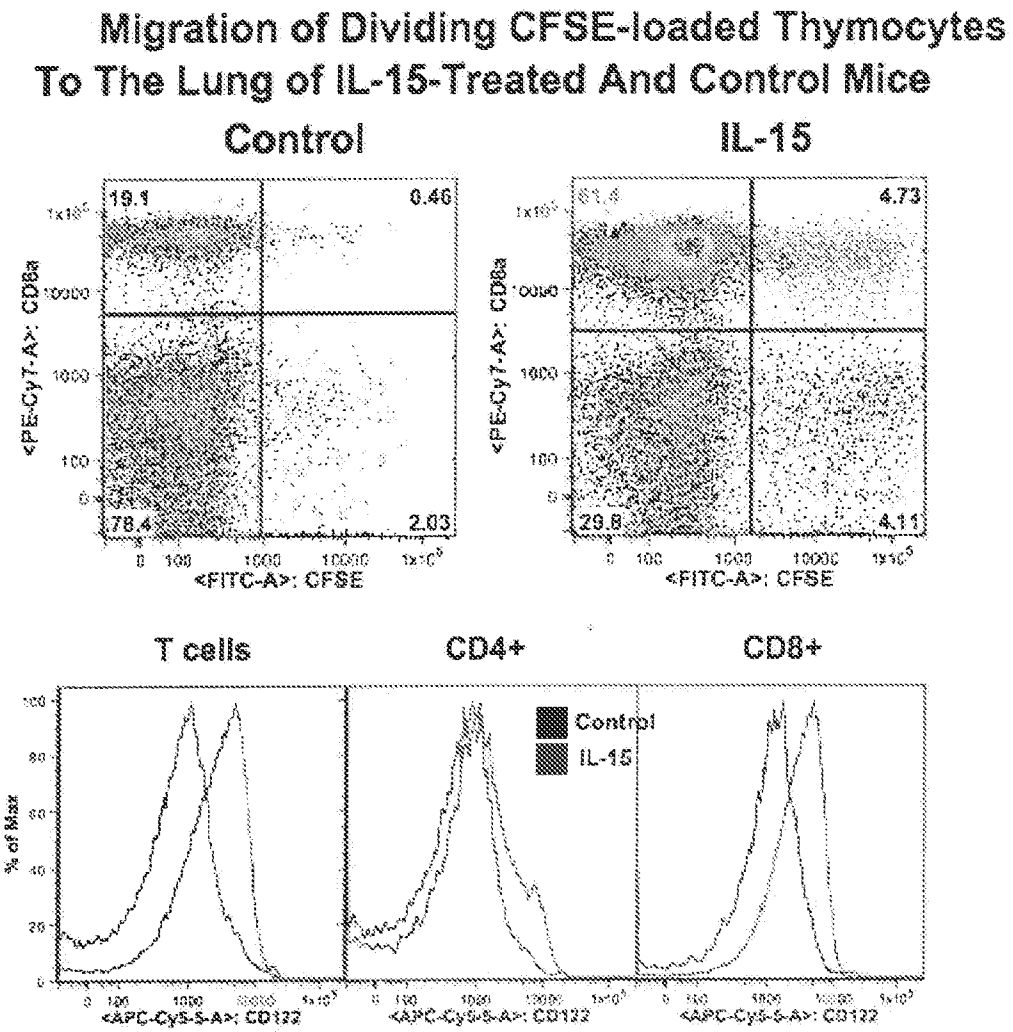

Migration of Dividing CFSE-loaded Thymocytes
To The Lung of IL-15-Treated And Control Mice
Control
IL-15
19.1
0.46
78.4
2.03
61.6
4.73
29.8
4.11
<PE-Cy7-A>: CD8a
<FITC-A>: CFSE
T cells
CD4+
CD8+
Control
IL-15
% of Max
<APC-Cy5-5-A>: CD122

Figure 5

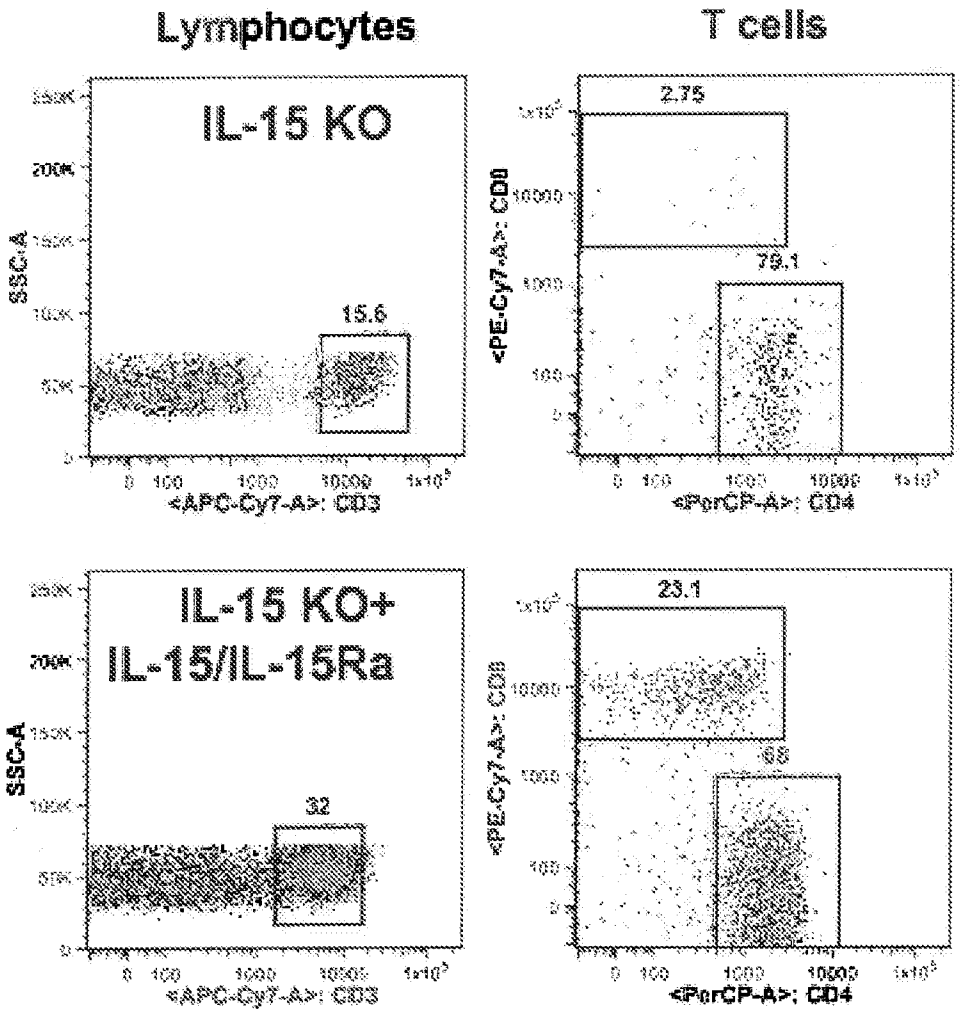

Lymphocytes
T cells
IL-15 KO
SSC-A
<APC-Cy7-A>: CD3
15.6
<PE-Cy7-A>: CD8
<PerCP-A>: CD4
2.75
79.1
IL-15 KO+
IL-15/IL-15Ra
32
23.1
68

Figure 6

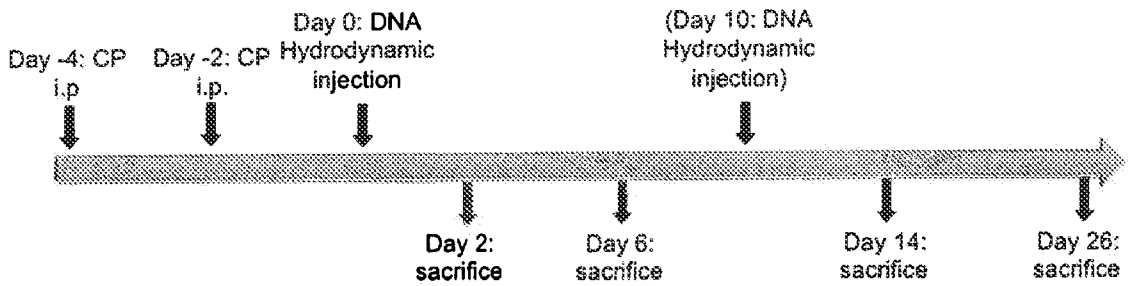

Day -4: CP i.p
Day -2: CP i.p.
Day 0: DNA Hydrodynamic injection
(Day 10: DNA Hydrodynamic injection)
Day 2: sacrifice
Day 6: sacrifice
Day 14: sacrifice
Day 26: sacrifice

Figure 7

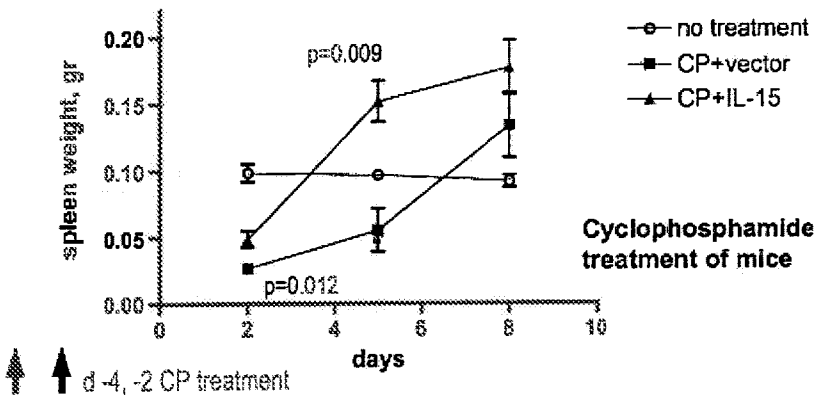

spleen weight, gr
0.20
0.15
0.10
0.05
0.00
p=0.009
p=0.012
0
2
4
6
8
10
days
no treatment
CP+vector
CP+IL-15
Cyclophosphamide
treatment of mice
d -4, -2 CP treatment

Figure 8

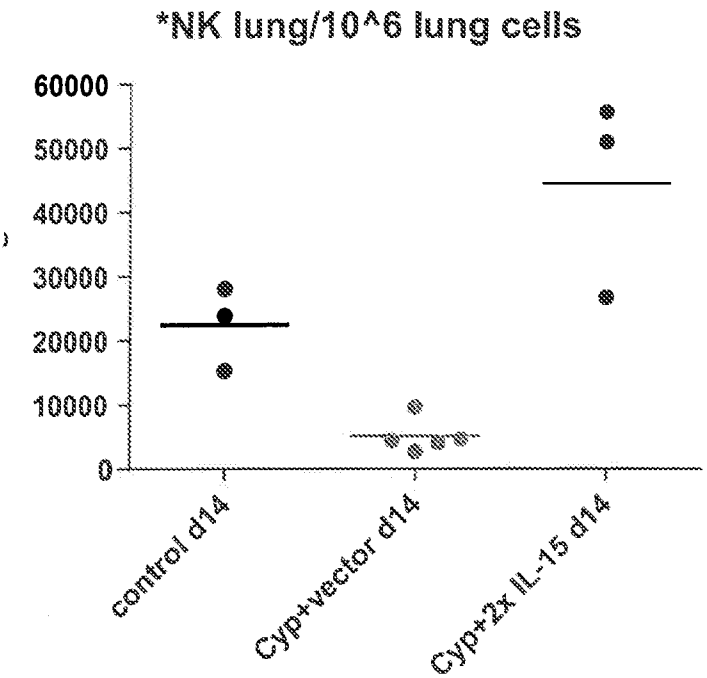

*NK lung/10^6 lung cells
60000
50000
40000
30000
20000
10000
0
control d14
Cyp+vector d14
Cyp+2x IL-15 d14

Figure 9

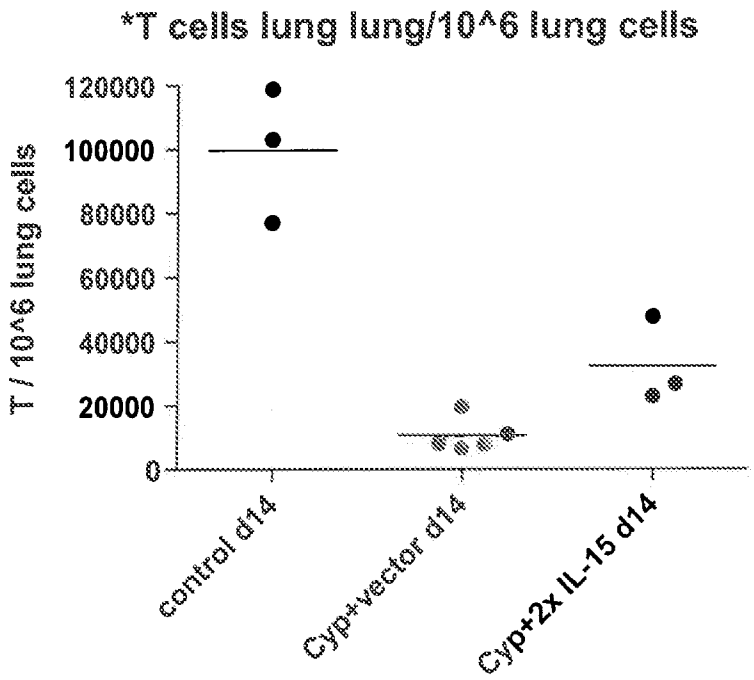

*T cells lung lung/10^6 lung cells
T / 10^6 lung cells
120000
100000
80000
60000
40000
20000
0
control d14
Cyp+vector d14
Cyp+2x IL-15 d14

Figure 10

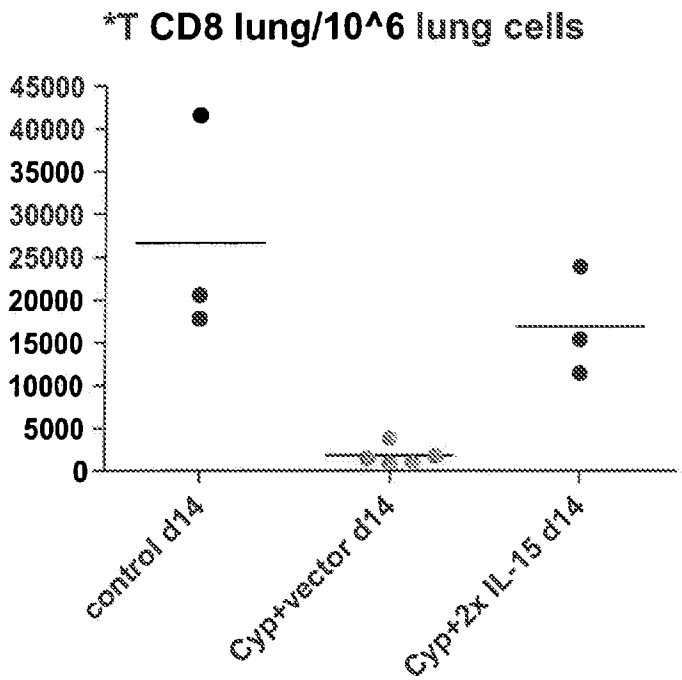

*T CD8 lung/10^6 lung cells
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
control d14
Cyp+vector d14
Cyp+2x IL-15 d14

Figure 11

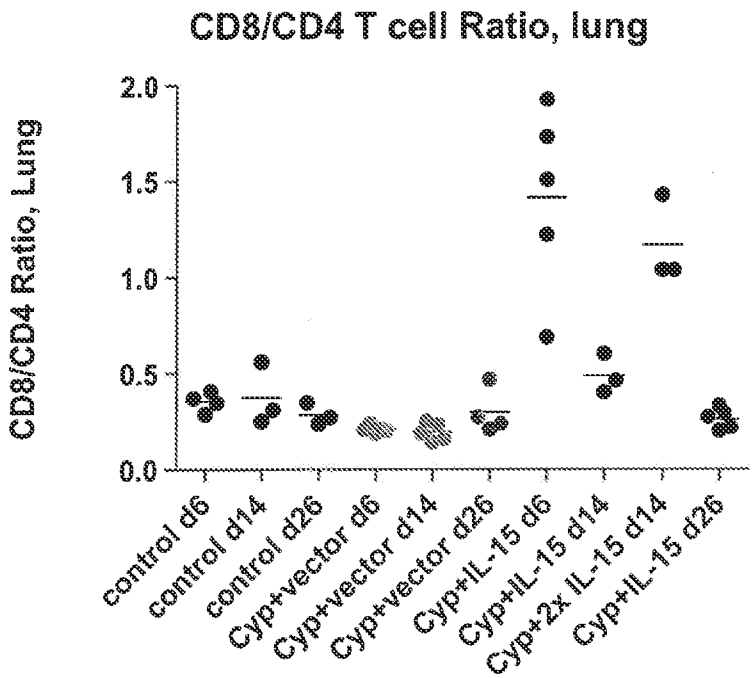

CD8/CD4 T cell Ratio, lung
CD8/CD4 Ratio, Lung
2.0
1.5
1.0
0.5
0.0
control d6
control d14
control d26
Cyp+vector d6
Cyp+vector d14
Cyp+vector d26
Cyp+IL-15 d6
Cyp+IL-15 d14
Cyp+2x IL-15 d14
Cyp+IL-15 d26

Figure 12

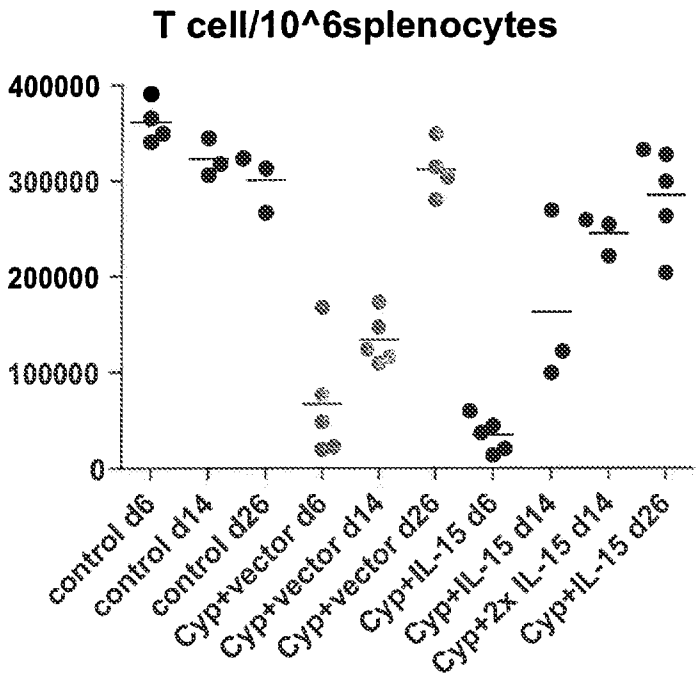

T cell/10^6splenocytes
400000
300000
200000
100000
0
control d6
control d14
control d26
Cyp+vector d6
Cyp+vector d14
Cyp+vector d26
Cyp+IL-15 d6
Cyp+IL-15 d14
Cyp+2x IL-15 d14
Cyp+IL-15 d26

Figure 13

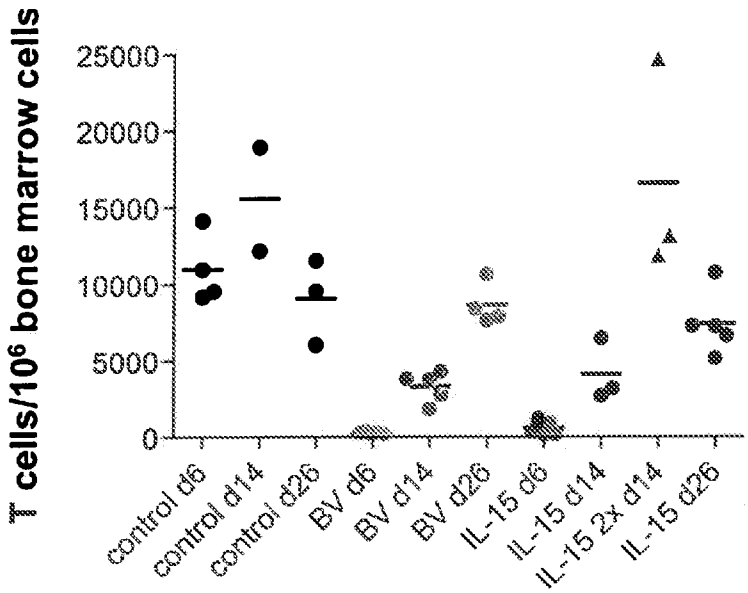

T cells/10^6 bone marrow cells
25000
20000
15000
10000
5000
0
control d6
control d14
control d26
BV d6
BV d14
BV d26
IL-15 d6
IL-15 d14
IL-15 2x d14
IL-15 d26

Figure 14

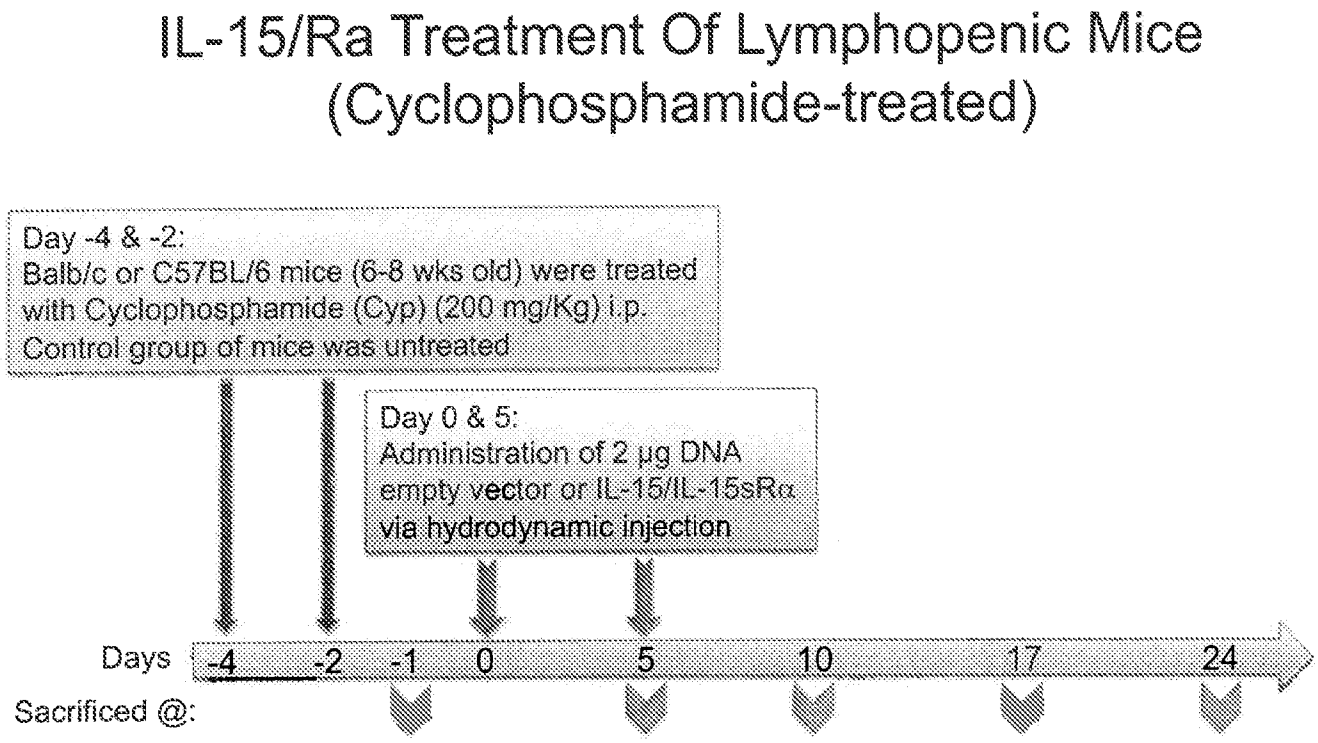
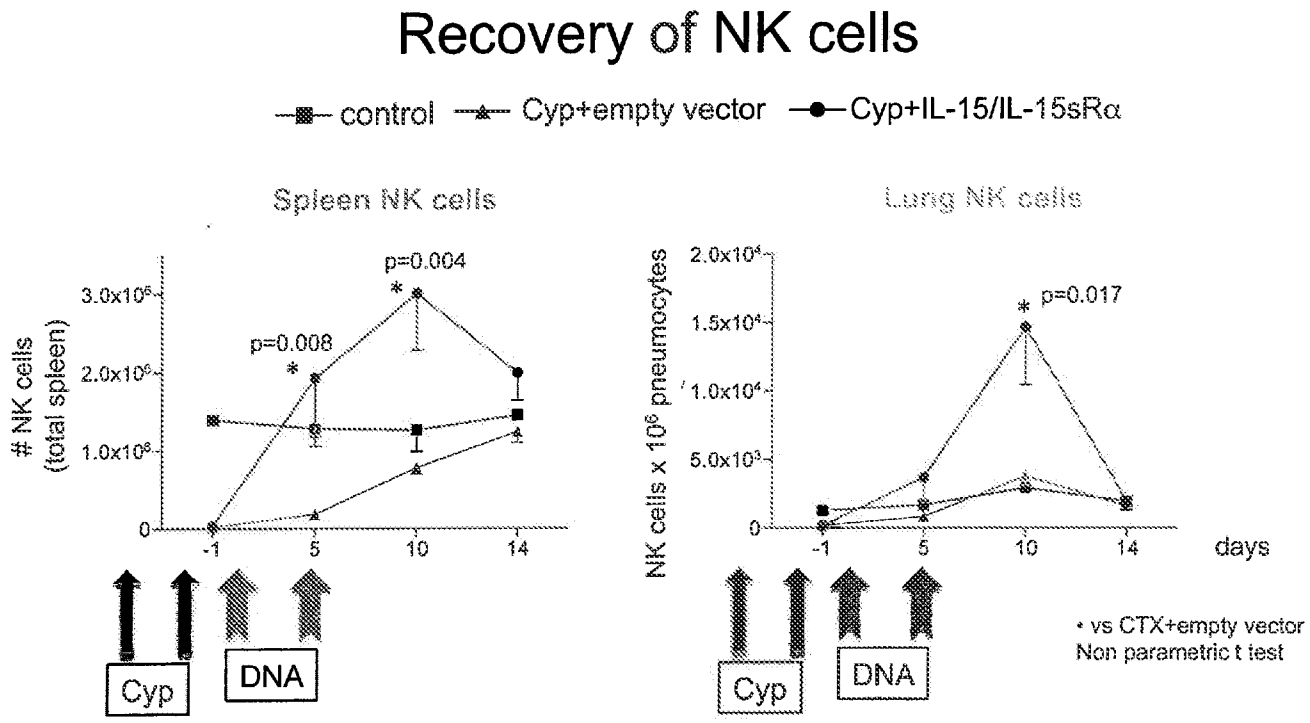
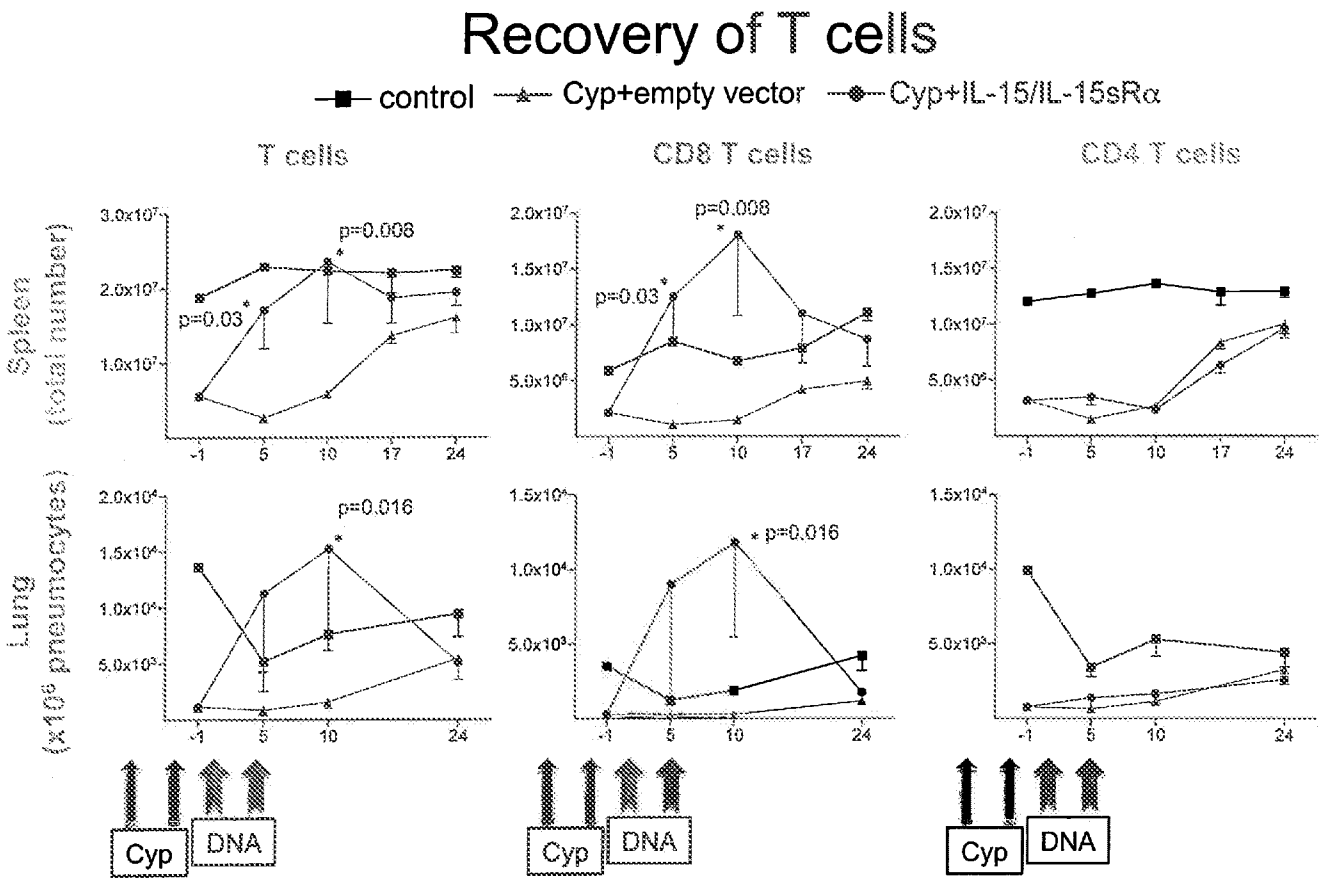

IL-15/Ra Treatment Of Lymphopenic Mice
(Cyclophosphamide-treated)
Day -4 & -2:
Balb/c or C57BL/6 mice (6-8 wks old) were treated
with Cyclophosphamide (Cyp) (200 mg/Kg) i.p.
Control group of mice was untreated
Day 0 & 5:
Administration of 2 µg DNA
empty vector or IL-15/IL-15sRα
via hydrodynamic injection
Days
-4
-2
-1
0
5
10
17
24
Sacrificed @:

Figure 15



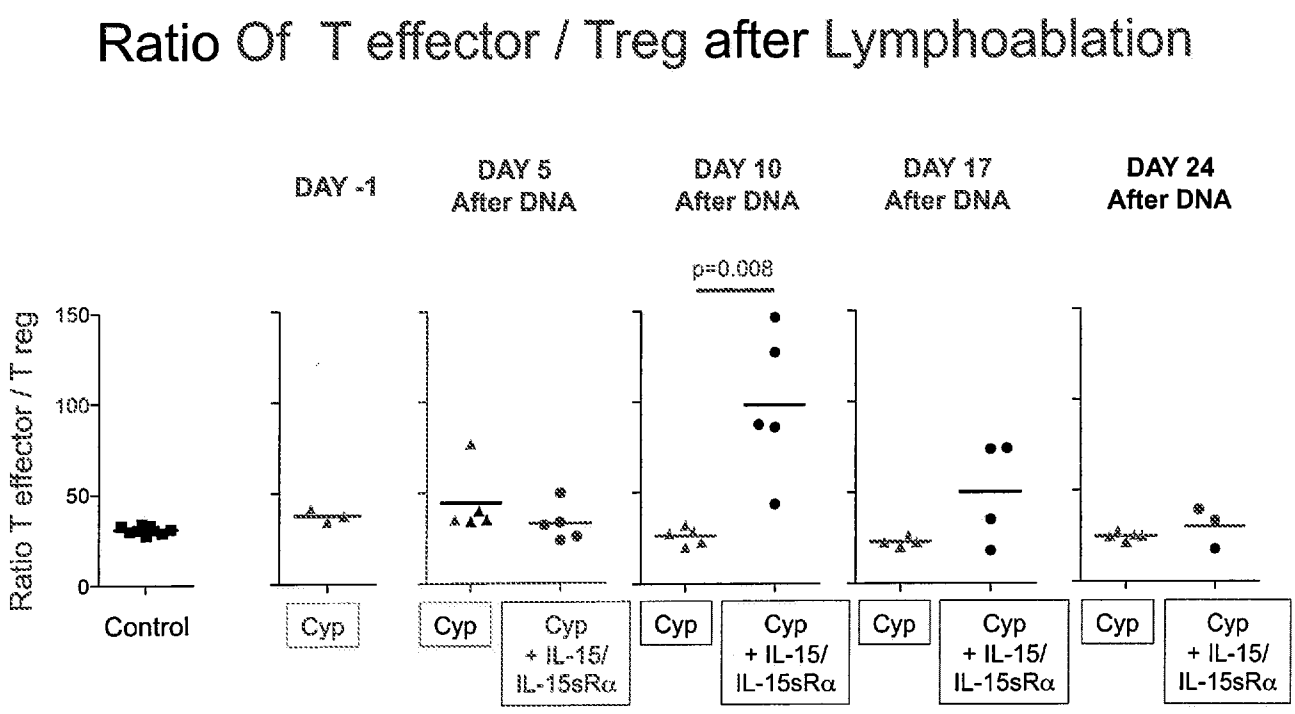
Single administration of IL-15/IL-15sRα-encoding DNA is sufficient for the complete recovery of NK cells in spleen and lung 5 days after DNA injection

Figure 16



IL-15/IL-15sRα administration promotes the recovery of CD8 T cells within 10 days after treatment, without affecting significantly the recovery of CD4 T cells

Figure 17



- High levels of circulating IL-15/IL-15sRα promote a transient increase in the Teffector/Treg ratio

Figure 18

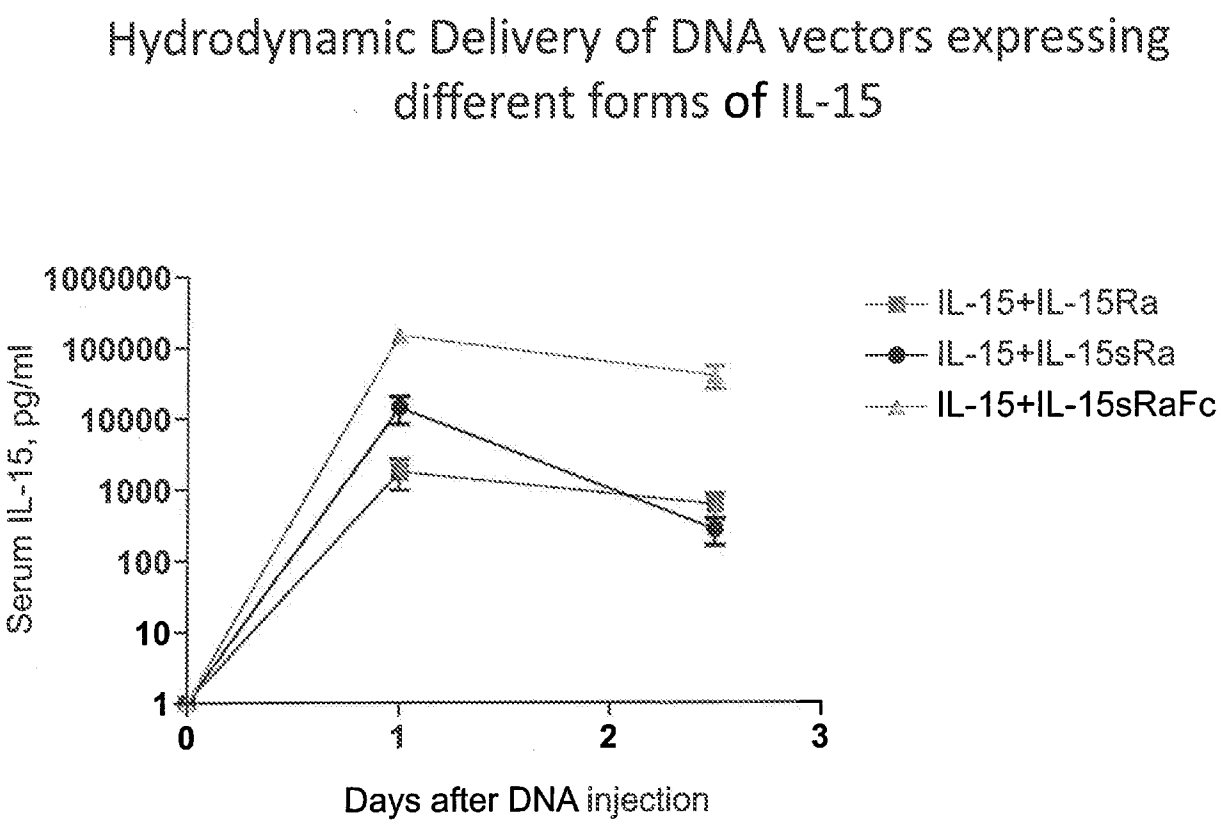

Hydrodynamic Delivery of DNA vectors expressing different forms of IL-15
Serum IL-15, pg/ml
1000000
100000
10000
1000
100
10
1
0
1
2
3
Days after DNA injection
IL-15+IL-15Ra
IL-15+IL-15sRa
IL-15+IL-15sRaFc

Figure 19

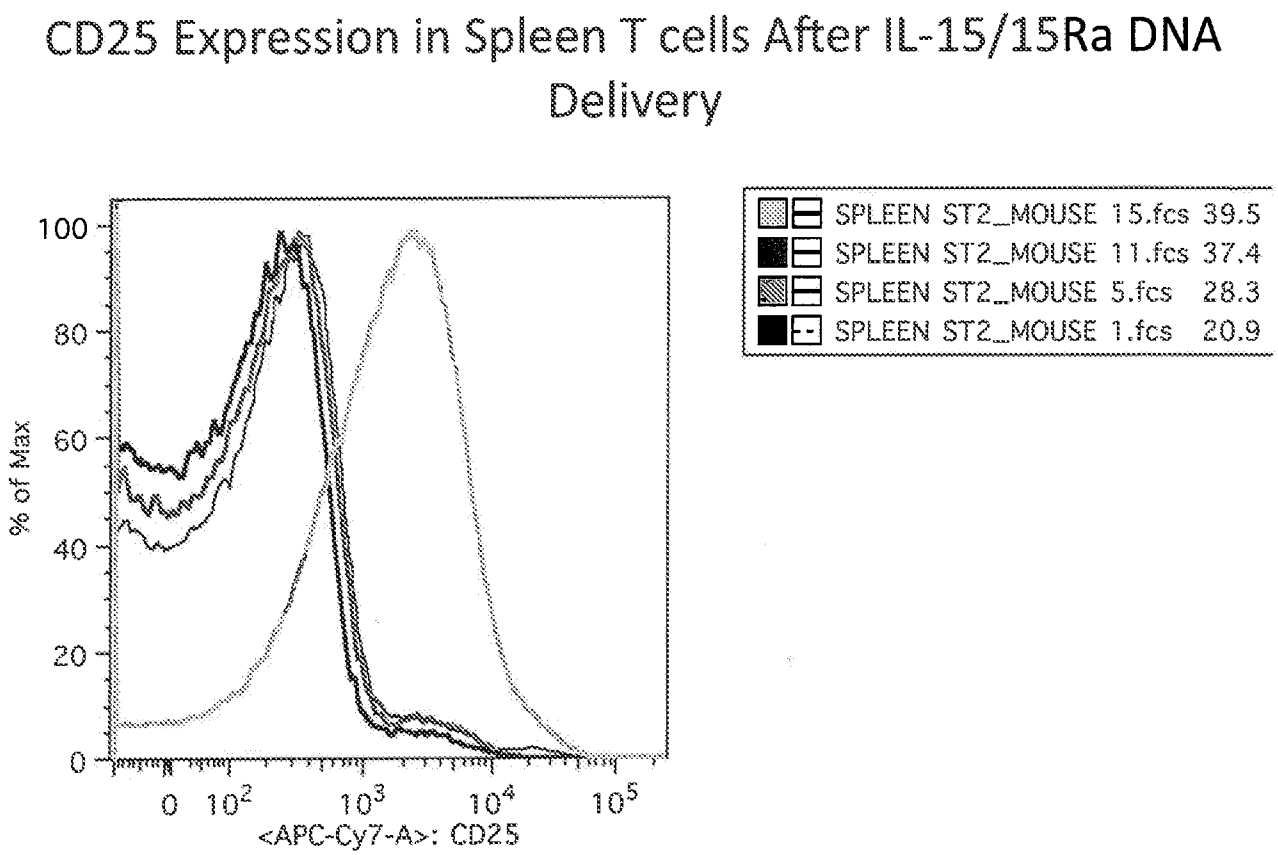

CD25 Expression in Spleen T cells After IL-15/15Ra DNA Delivery
SPLEEN ST2_MOUSE 15.fcs 39.5
SPLEEN ST2_MOUSE 11.fcs 37.4
SPLEEN ST2_MOUSE 5.fcs 28.3
SPLEEN ST2_MOUSE 1.fcs 20.9
% of Max
100
80
60
40
20
0
0 10^2 10^3 10^4 10^5
<APC-Cy7-A>: CD25

Figure 20

Expression of CD62L On The Surface Of Spleen T Cells
After IL-15/15Ra DNA Delivery

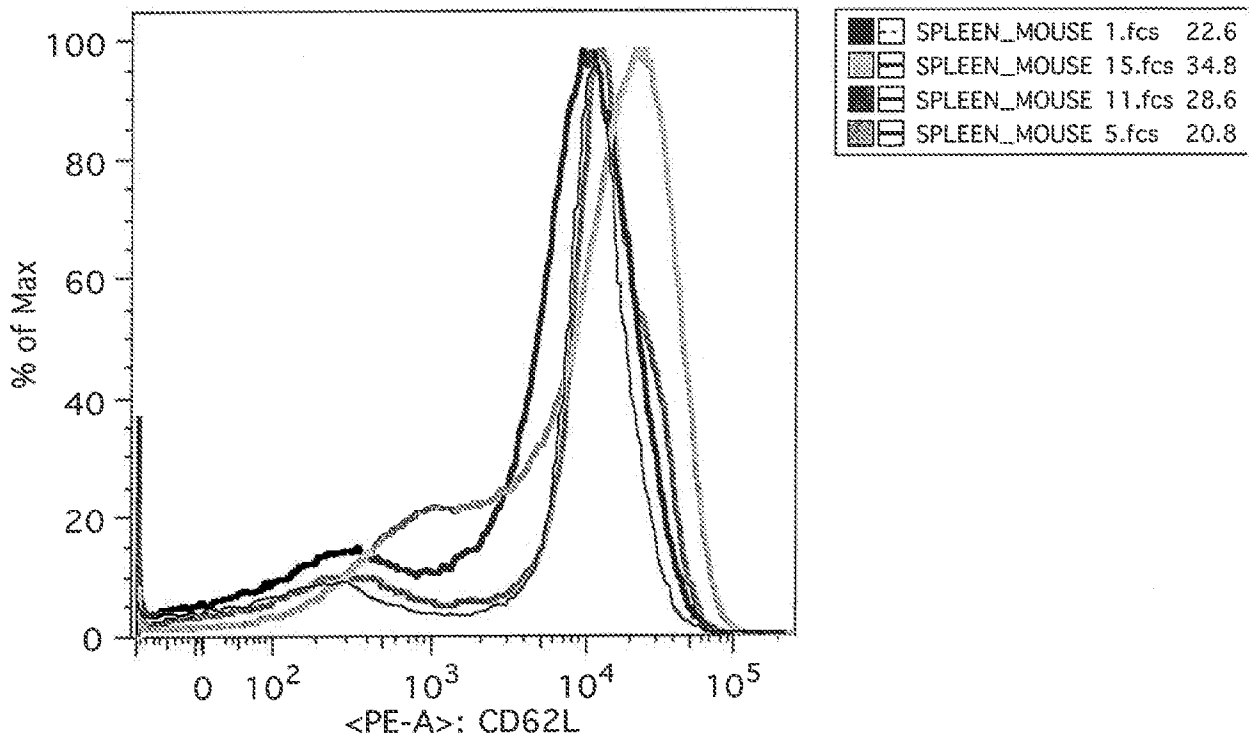


Figure 21

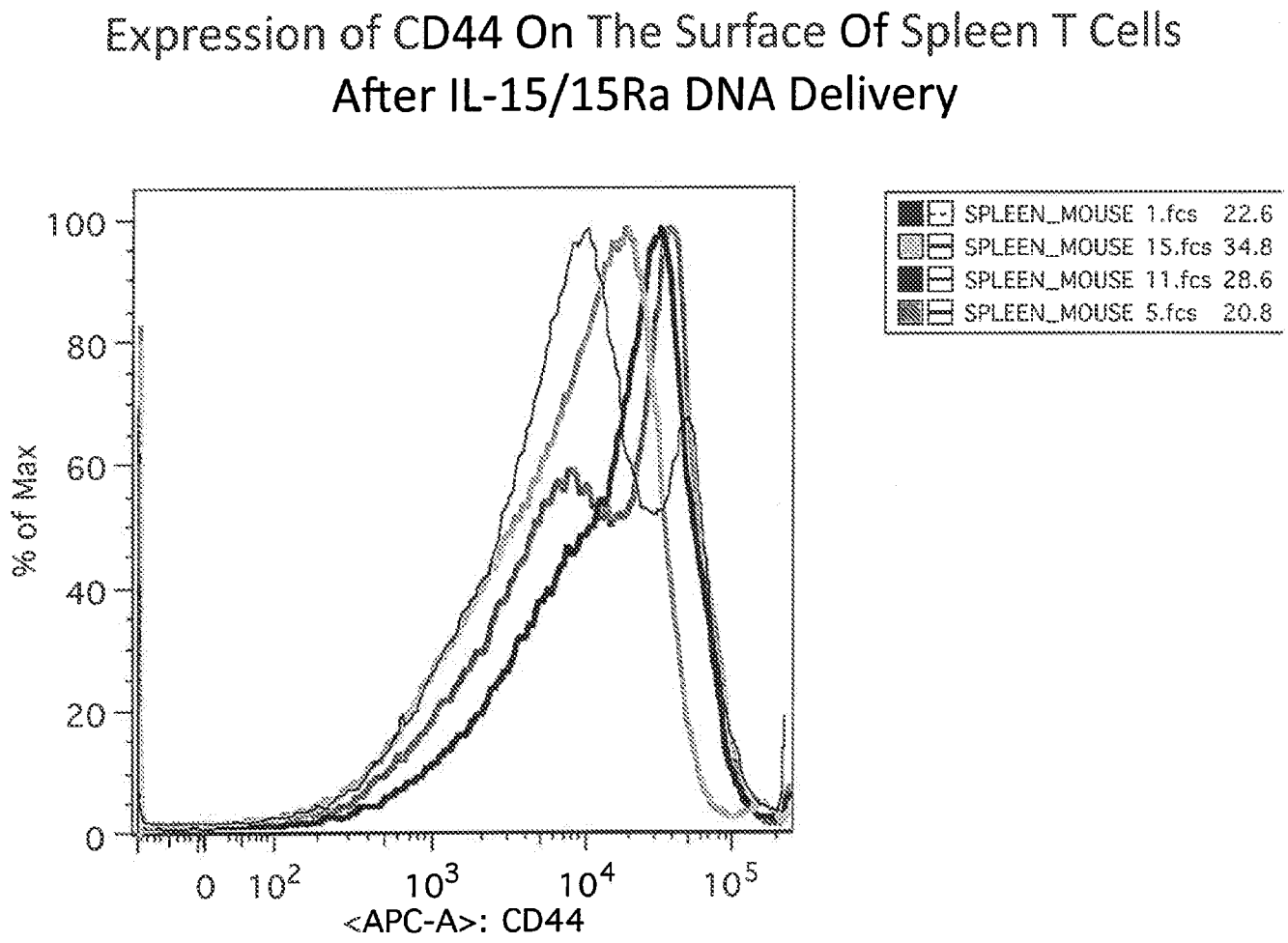

Expression of CD44 On The Surface Of Spleen T Cells
After IL-15/15Ra DNA Delivery
SPLEEN_MOUSE 1.fcs 22.6
SPLEEN_MOUSE 15.fcs 34.8
SPLEEN_MOUSE 11.fcs 28.6
SPLEEN_MOUSE 5.fcs 20.8
% of Max
100
80
60
40
20
0
0
10^2
10^3
10^4
10^5
<APC-A>: CD44

Figure 22

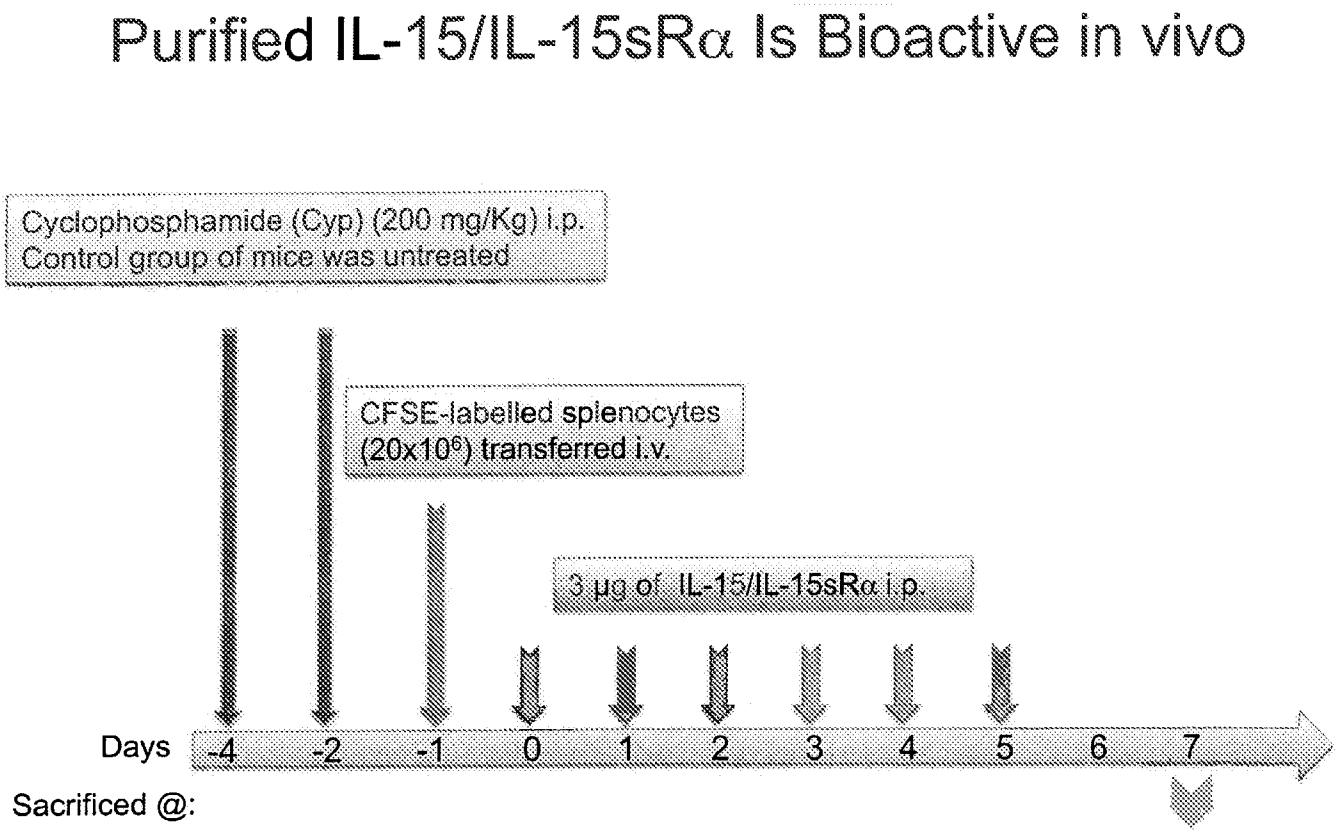
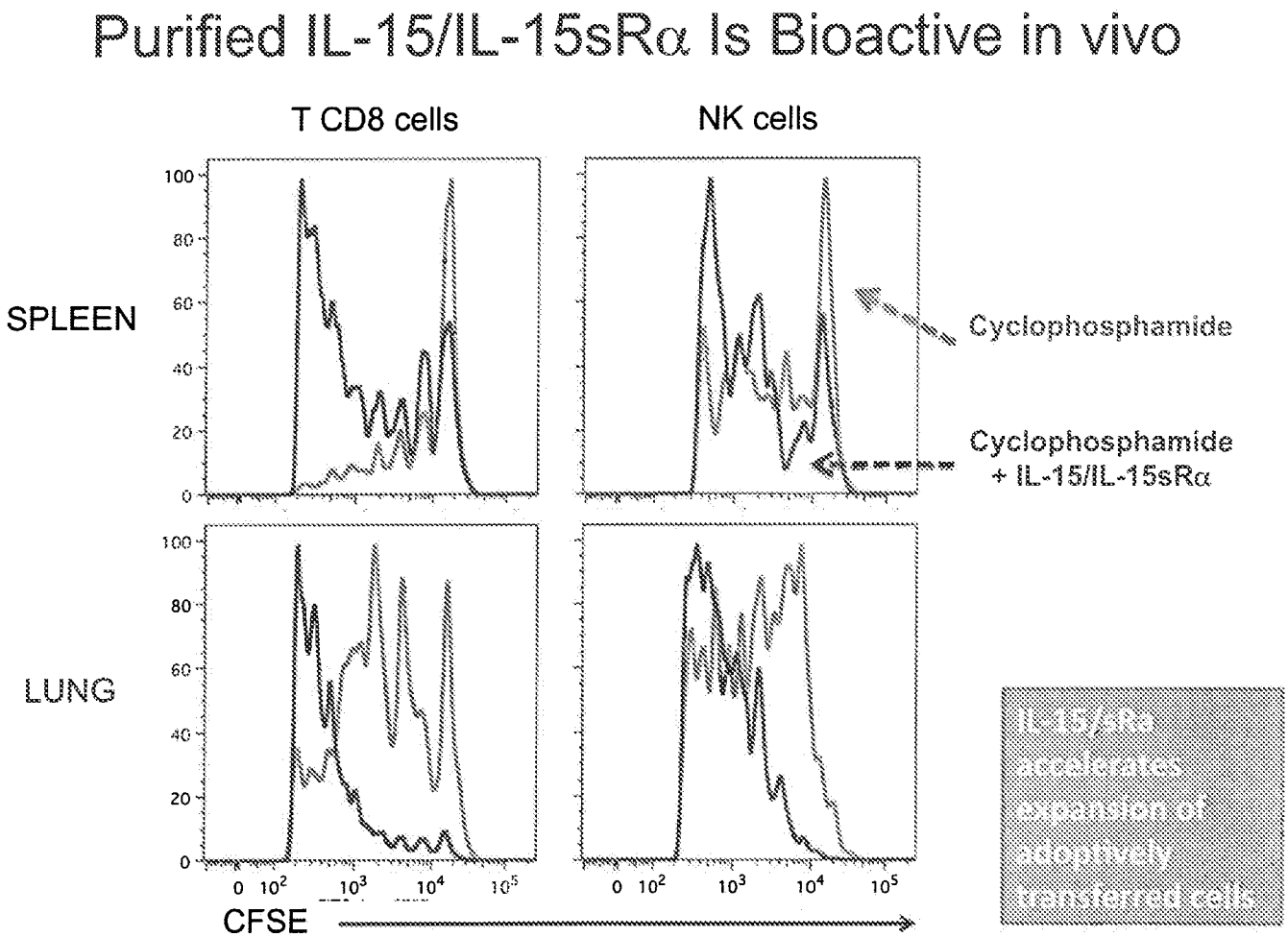

Purified IL-15/IL-15sRα Is Bioactive in vivo
Cyclophosphamide (Cyp) (200 mg/Kg) i.p.
Control group of mice was untreated
CFSE-labelled splenocytes
(20x10⁶) transferred i.v.
3 µg of IL-15/IL-15sRα i.p.
Days
-4
-2
-1
0
1
2
3
4
5
6
7
Sacrificed @:

Figure 23


Purified IL-15/IL-15sRα Is Bioactive in vivo
T CD8 cells
NK cells
SPLEEN
LUNG
Cyclophosphamide
Cyclophosphamide + IL-15/IL-15sRα
CFSE
IL-15/ARα accelerates expansion of adoptively transferred cells

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/045511

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61K38/20 A61K47/48 A61K48/00 A61P37/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61K A61P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, BIOSIS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/084342 A2 (US GOV HEALTH & HUMAN SERV [US]; FELBER BARBARA K [US]; PAVLAKIS GEORG) 26 July 2007 (2007-07-26)	1-37, 41-50
Y	see abstract. claims 11-13,28,38-47, paragraphs [0032] [0137] [0166], examples 3 and 4	1-50
X	US 2006/257361 A1 (WATANABE MORIHIRO [US] ET AL) 16 November 2006 (2006-11-16)	1-5, 9-12, 14-20, 23,24, 27,41, 43,44, 47,49,50
Y	see claims and [0032]	1-50

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 October 2010	11/11/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Merckling-Ruiz, V

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/045511

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/160578 A1 (WALDMANN THOMAS A [US] ET AL) 12 July 2007 (2007-07-12)	1-28, 41-50
Y	see [0007], [0047]-[0050], examples 1-2 and 5-8	1-50

X	JALAH RASHMI ET AL: "Efficient systemic expression of bioactive IL-15 in mice upon delivery of optimized DNA expression plasmids" DNA AND CELL BIOLOGY, MARY ANN LIEBERT, NEW YORK, NY, US LNKD- DOI:10.1089/DNA.2007.0645, vol. 26, no. 12, 1 December 2007 (2007-12-01), pages 827-840, XP002522130 ISSN: 1044-5498	1-5,9, 12-20, 24,27,28
Y	* abstract	1-50

Y	WILLIAMS ET AL: "T cell immune reconstitution following lymphodepletion" SEMINARS IN IMMUNOLOGY, W.B. SAUNDERS COMPANY, PA, US LNKD- DOI:10.1016/J.SMIM.2007.10.004, vol. 19, no. 5, 19 November 2007 (2007-11-19), pages 318-330, XP022371005 ISSN: 1044-5323 see abstract, pages 322-323 and page 324 right col.	1-50

X	ALPDOGAN O. ET AL.: "Interleukin-15 enhances immune reconstitution after allogeneic bone marrow transplantation." BLOOD, vol. 15, January 2005 (2005-01), pages 865-873, XP002604499	1-6, 8-12, 14-20, 23,27
Y	see abstract	1-50

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2010/045511

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2007084342 A2	26-07-2007	AU 2007207785 A1	26-07-2007
		CA 2636111 A1	26-07-2007
		EP 1984505 A2	29-10-2008
		JP 2009523420 T	25-06-2009
		US 2009082299 A1	26-03-2009
US 2006257361 A1	16-11-2006	NONE	
US 2007160578 A1	12-07-2007	NONE	