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Humanizált IL-7 rágcsálók

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(54) **Humanized IL-7 rodents**

Humanisierte IL-7-Nagetiere

Rongeurs à IL-7 humanisée

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Description**FIELD**

[0001] Non-human animals (*e.g.*, mammals, *e.g.*, rodents such as mice, rats, and hamsters) that comprise a genetic modification comprising a replacement, at an endogenous locus, of a non-human IL-7 gene sequence with a human IL-7 gene sequence. Rodents and other non-human animals that express human IL-7 or humanized IL-7 from a locus under control of endogenous non-human regulatory sequences, or from an endogenous non-human IL-7 locus that comprises endogenous non-human regulatory sequences.

BACKGROUND

[0002] Transgenic mice that have randomly inserted transgenes that contain a human IL-7 sequence are known in the art. However, most if not all of these transgenic mice are not optimal in one aspect or another. For example, most mice transgenic for human IL-7 exhibit abnormal levels and/or ratios of certain cells, including T cells, that are likely due to a dysregulation of immune cell development, *e.g.*, T cell development.

[0003] There remains a need in the art for non-human animals that comprise human IL-7-encoding sequences, wherein the human IL-7 encoding sequences are at an endogenous non-human IL-7 locus, and for non-human animals that express human IL-7 under the control of endogenous non-human regulatory elements. There is a need in the art for non-human animals that express human IL-7 in a manner that is as physiologically relevant in the non-human animal as possible. There is a need in the art for non-human animals that express a human IL-7, wherein the non-human animals lack a significant abnormality in peripheral T cells, and/or in ratios of T cell subtypes.

O'Connell et al (PLOS ONE vol. 5, no. 8 e12009 (2010) describes lentiviral delivery of human Interleukin-7 to human immune system mice. Aguila et al (Journal of Bone and Mineral Research, vol. 27, no. 5, 1030-1042 (2012) describes osteoblast-specific overexpression of human interleukin-7. Rathinam et al (Blood, vol 118, no. 11, 3119-3128 (2011)) describes differentiation and function of human macrophages in humanized CSF-1 mice.

SUMMARY

[0004] The present invention provides a genetically modified rodent comprising in its germline a replacement of rodent IL-7 exons 2 through 5 with human IL-7 exons 2 through 6 to form a human or humanized IL-7-encoding gene, wherein the replacement is at an endogenous rodent IL-7 locus, wherein the human or humanized IL-7-encoding gene is under control of endogenous rodent IL-7 regulatory elements. The invention further provides a method for making a rodent with a human or humanized IL-7-encoding gene, comprising modifying the germline of the rodent by replacement of rodent IL-7 exons 2 through 5 with human IL-7 exons 2 through 6 to form a human or humanized IL-7-encoding gene flanked upstream and downstream with endogenous rodent IL-7 regulatory sequences, wherein the modification is at an endogenous rodent IL-7 locus. The invention additionally provides a humanized IL-7 locus comprising a rodent IL-7 exon 1, a human IL-7 exon 2, a human IL-7 exon 3, a human IL-7 exon 4, a human IL-7 exon 5 and a human IL-7 exon 6, wherein the humanized IL-7 locus optionally further comprises 5' and 3' rodent IL-7 untranslated regions flanking the rodent IL-7 exon 1 and human IL-7 exon 6, and wherein the humanized IL-7 locus optionally also further comprises a 3' human untranslated region, or portion thereof, that is contiguous with a rodent 3' untranslated region. The invention also provides a cell comprising a humanized IL-7 locus of the invention and tissue isolated from a rodent of the invention, comprising the replacement at an endogenous rodent IL-7 locus of the rodent of the invention.

[0005] Genetically modified non-human animals, cells, tissues, and nucleic acids are described that comprise a human IL-7 genomic sequence at an endogenous non-human IL-7 locus. The non-human animals express a humanized IL-7 protein from a modified locus regulated by one or more endogenous non-human regulatory sequences of the modified endogenous IL-7 locus. In various embodiments, the non-human animals are rodents, *e.g.*, mice, rats, hamsters, *etc.* In a specific embodiment, the rodent is a mouse or a rat.

[0006] In various aspects, the non-human animals comprise a modified IL-7 gene in the germline of the non-human animal at a modified endogenous IL-7 locus, wherein the modified endogenous IL-7 locus comprises a humanization of at least a portion of the endogenous IL-7 gene. The mice are heterozygous or homozygous with respect to the modified IL-7 locus. A non-human animal is described that comprises a lack of a first endogenous IL-7 allele and a humanization of a second endogenous IL-7 allele. In various aspects, the humanization is of one or more exons and/or introns. In various aspects, non-human animals having a modified IL-7 locus are described wherein one or both of an endogenous non-human 5'-untranslated region and an endogenous non-human 3'-untranslated region are retained in the modified animal.

[0007] In some aspects, non-human animals described herein comprise a 5'-untranslated region contained within SEQ ID NO: 1 In some aspects, non-human animals described herein comprise a 3'-untranslated region contained within

SEQ ID NO: 2. In some aspects, non-human animals described herein comprises a 5'-untranslated region contained within SEQ ID NO: 1 and a 3'-untranslated region contained within SEQ ID NO: 2.

[0008] In some aspects, non-human animals described herein comprise a 5'-untranslated region that is SEQ ID NO: 1. In some aspects, non-human animals described herein comprise a 3'-untranslated region that is SEQ ID NO: 2. In some aspects, non-human animals described herein comprise a 5'-untranslated region that is SEQ ID NO: 1 and a 3'-untranslated region that is SEQ ID NO: 2.

[0009] In some aspects, a humanized IL-7 gene described herein has a sequence that is at least 50% (e.g., 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or more) identical to a continuous sequence comprising exons 2-6 of a human IL-7 gene. In some certain aspects, a human IL-7 gene described herein comprises SEQ ID NO: 3. In some aspects, a humanized IL-7 gene described herein has a sequence that reflects a humanization as set forth in Figure 1.

[0010] In one aspect, a genetically modified rodent is described herein that comprises a replacement at an endogenous rodent IL-7 locus of an endogenous rodent IL-7 genomic sequence with a human IL-7 genomic sequence.

[0011] In one aspect, the genetically modified rodent comprises a first rodent regulatory sequence upstream (with respect to the direction of transcription of the IL-7 gene) of the human IL-7 genomic sequence and a second rodent regulatory sequence downstream of the human IL-7 genomic sequence. In one aspect, the first rodent regulatory sequence comprises a rodent promoter and/or enhancer, and the second rodent regulatory sequence comprises a 3'-UTR.

[0012] In one aspect, the rodent is a mouse and comprises an endogenous mouse IL-7 gene locus having a mouse exon 1 and human exons 2, 3, 4, 5, and 6. In one aspect, the endogenous mouse IL-7 gene locus comprises, from upstream to downstream with respect to the direction of transcription, mouse exon 1, at least a portion of a first mouse intron, and a contiguous human genomic fragment comprising human exon 2 through human exon 6. In one aspect, the mouse further comprises a contiguous sequence of endogenous mouse DNA comprising an complete endogenous mouse IL-7 upstream (with respect to the direction of transcription of the IL-7 gene) promoter and regulatory region, wherein the contiguous mouse DNA is upstream of the human genomic fragment; and further comprises a contiguous sequence of endogenous mouse DNA 3'-UTR downstream of the human genomic fragment.

[0013] In one aspect, the mouse comprises a mouse sequence that is at least 90%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99% identical with a sequence selected from SEQ ID NO: 1, SEQ ID NO:2, and a combination thereof. In a specific aspect, the mouse comprises a mouse sequence selected from SEQ ID NO:1 and SEQ ID NO:2

[0014] In one aspect, a genetically modified mouse is described herein that comprises a replacement at an endogenous mouse IL-7 locus of an endogenous mouse IL-7 genomic sequence with a human IL-7 genomic sequence to form a modified locus, wherein the human IL-7 genomic sequence comprises at least one human exon, and the modified locus comprises a mouse sequence selected from a sequence of SEQ ID NO:1, SEQ ID NO:2, and a combination thereof.

[0015] In one aspect, the replacement comprises a human genomic fragment comprising exons 2 through 6, and the human genomic fragment is linked to mouse exon 1 to form a modified endogenous mouse IL-7 locus, wherein the modified mouse IL-7 locus comprises a mouse sequence selected from SEQ ID NO:1, SEQ ID NO:2, and a combination thereof.

[0016] In one aspect, a genetically modified rodent is described herein that comprises an IL-7 gene that comprises a rodent exon 1 and at least a portion of a rodent intron 1, and a human IL-7 gene sequence of human IL-7 exons 2, 3, 4, 5, and 6, wherein the rodent comprises a sequence selected from a rodent upstream IL-7 regulatory sequence, a rodent IL-7 3'-UTR, and a combination thereof.

[0017] In one aspect, a genetically modified mouse is described herein that comprises a sequence selected from SEQ ID NO:1, SEQ ID NO:2, and a combination thereof; wherein the mouse lacks an endogenous sequence encoding exons 2 through 5 of a mouse IL-7 protein, and the mouse comprises a nucleic acid sequence at an endogenous mouse IL-7 locus wherein the nucleic acid sequence encodes human IL-7 exons 2, 3, 4, 5, and 6.

[0018] In one aspect, a genetically modified rodent is described herein that expresses a human or humanized IL-7 protein from an endogenous rodent IL-7 locus that is modified to express at least one human IL-7 exon. In one aspect, the rodent IL-7 locus is modified to express a human or humanized IL-7 protein encoded by a sequence comprising at least two human IL-7 exons. In one aspect, the rodent IL-7 locus is modified to express a human or humanized IL-7 protein encoded by a sequence comprising at least three human IL-7 exons. In one aspect, the rodent IL-7 locus is modified to express a human or humanized IL-7 protein encoded by a sequence comprising at least human IL-7 exons 2, 3, 4, 5, and 6 (*i.e.*, 2 through 6). In one embodiment, the rodent IL-7 locus is modified to express a human IL-7 protein. In some certain aspects, the rodent IL-7 locus is modified to express a human IL-7 protein whose sequence reflects a protein encoded by a locus as shown in Figure 1. In some certain aspects, the rodent IL-7 locus is modified to express a human IL-7 protein comprising a sequence encoded by exons 2-6 of a human IL-7 gene. In some certain aspects, the rodent IL-7 locus is modified to express a human IL-7 protein comprising a sequence encoded by exons 2-6 of a human IL-7 gene as set forth in SEQ ID NO: 3.

[0019] In one aspect, a genetically modified rodent is described herein that expresses a human or humanized IL-7

protein from an endogenous rodent IL-7 locus that is modified to comprise at least human IL-7 exons 2 through 6 in place of rodent IL-7 exons 2 through 5.

[0020] In one aspect, a genetically modified rodent is described herein that expresses a human or humanized IL-7 protein from a humanized endogenous rodent IL-7 locus comprising a humanized endogenous rodent IL-7 coding region, wherein the humanized endogenous rodent IL-7 locus comprises all endogenous rodent regulatory elements that are present in a wild-type rodent upstream of a wild-type rodent IL-7 coding region and that are downstream of the wild-type rodent IL-7 coding region.

[0021] In one aspect, a genetically modified rodent is described herein that expresses a human or humanized IL-7 protein from a humanized rodent IL-7 locus that comprises rodent regulatory regions upstream and downstream of a nucleic acid sequence encoding the human or humanized IL-7 protein, wherein the human or humanized IL-7 protein is expressed in an expression pattern that is about the same as the expression pattern of a rodent IL-7 protein in a wild-type rodent. In one embodiment, the level of serum expression of the human or humanized IL-7 is about the same as the level of serum expression of a rodent IL-7 protein in a wild-type rodent.

[0022] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the lymphocyte population of the rodent is characterized by its B cell population that is about the same in number as a population of B cells in an age-matched wild-type mouse. In one aspect, the modified rodent is characterized by a population of mature B cells that is about the same in number as a population of mature B cells in an age-matched wild-type mouse. In one aspect, the humanized IL-7 protein is identical to a human IL-7 protein. In one aspect, the humanized IL-7 protein comprises human sequence encoded by at least exons 2 through 6 of a human IL-7 gene.

[0023] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the lymphocyte population of the rodent is characterized by a population of T cells that is about the same in number as a population of T cells in an age-matched wild-type mouse. In one aspect, the modified rodent exhibits a population of mature T cells that is about the same in number as a population of mature T cells in an age-matched wild-type mouse. In one aspect, the modified rodent exhibits a population of peripheral T cells that is about the same in number as the population of peripheral T cells in an age-matched wild-type mouse. In one aspect, the humanized IL-7 protein is identical to a human IL-7 protein. In one aspect, the humanized IL-7 protein comprises human sequence encoded by at least exons 2 through 6 of a human IL-7 gene.

[0024] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the lymphocyte population of the rodent is characterized by a T cell population that exhibits a CD4:CD8 ratio that is about the same as the CD4:CD8 ratio in the T cell population of an age-matched wild-type mouse. In one aspect, the humanized IL-7 protein is identical to a human IL-7 protein. In one aspect, the humanized IL-7 protein comprises human sequence encoded by at least exons 2 through 6 of a human IL-7 gene.

[0025] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the rodent comprises a characteristic selected from a lack of a propensity to develop a chronic colitis; lack of over-expression of IL-7 in colonic mucosal lymphocytes; normal, or wild-type, expression of IL-7 in colonic mucosal lymphocytes; lacks a severe dermatitis; lacks a dermatitis characterized by a massive dermal infiltration of mononuclear cells; exhibits a CD4:CD8 ratio in its T cell population that is about the same as the CD4:CD8 ratio of an age-matched wild-type mouse; exhibits an expression pattern of human IL-7 that is about the same as an expression pattern of mouse IL-7 in a wild-type mouse; and a combination thereof.

[0026] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the rodent lacks a propensity to develop a chronic colitis.

[0027] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the rodent does not exhibit over-expression of IL-7 in colonic mucosal lymphocytes.

[0028] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the rodent does not exhibit a dermatitis characterized by a massive dermal infiltration of mononuclear cells.

[0029] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the rodent does not exhibit a lymphoproliferation into dermis.

[0030] In one aspect, a genetically modified rodent is described herein that expresses a humanized IL-7 protein, wherein the rodent does not exhibit B and/or T cell lymphomas at a higher frequency than an age-matched wild-type mouse.

[0031] In one aspect, a genetically modified mouse is described herein that expresses a humanized IL-7 protein, or a human IL-7 protein, wherein the mouse is no more prone than a wild-type mouse to developing a pathology selected from colitis, chronic colitis, severe dermatitis, pathological and/or massive infiltration of the dermis by mononuclear cells, lymphoproliferation of the dermis, B cell lymphomas, T cell lymphomas, reduction in the number of mature B and/or T cells, reduction in the number of peripheral B and/or T cells, abnormal numbers of CD4+ T cells, abnormal numbers of CD8+ T cells, and a combination thereof.

[0032] In some aspects, a genetically modified mouse is described herein that expresses a human IL-7 protein whose sequence reflects a replacement of a mouse IL-7 gene sequence with a human IL-7 gene sequence, wherein the human

IL-7 gene sequence comprises exons 2-6 of a human IL-7 gene. In some certain aspects, the replacement is of a sequence comprising exons 2-5 of a mouse IL-7 gene. In some certain aspects, a human IL-7 gene comprises SEQ ID NO:3. In some certain aspects, expression of the human IL-7 protein is under the control of mouse regulatory elements.

[0033] In some aspects, a genetically modified mouse is described herein that does not detectably express a mouse IL-7 protein. In some certain aspects, the genome of a mouse as described herein comprises a deletion in whole or in part of a mouse IL-7 gene. In some certain aspects, the genome of a mouse as described herein comprises a deletion of an endogenous IL-7 gene sequence corresponding to exons 2-5.

[0034] In one aspect, a genetically modified non-human animal is described herein, comprising, in its germline, a replacement of at least one non-human IL-7 exon with at least one human IL-7 exon to form a human or humanized IL-7-encoding gene, wherein the replacement is at an endogenous non-human IL-7 locus, wherein the human or humanized IL-7-encoding gene is under control of endogenous non-human regulatory elements.

[0035] The genetically modified non-human animal is a rodent. In one embodiment, the rodent is selected from a rat and a mouse.

[0036] In one aspect, the human or humanized IL-7-encoding gene described herein comprises human exons selected from the group consisting of human exon 1, human exon 2, human exon 3, human exon 4, human exon 5, human exon 6, and a combination thereof. In one aspect, the human or humanized IL-7-encoding gene comprises no more than five human exons.

[0037] In one aspect, the genetically modified non-human animal is a rodent that is a mouse and the modified locus comprises a replacement of mouse exons 2, 3, 4, and 5 with a human genomic segment comprising human IL-7 exons 2, 3, 4, 5, and 6.

[0038] In one aspect, the human or humanized IL-7-encoding gene comprises a cDNA encoding a human or humanized IL-7 protein.

[0039] In one aspect, a genetically modified non-human animal is described herein, comprising, in its germline, a transgene comprising a nucleic acid sequence encoding a human or humanized IL-7 gene, wherein the human or humanized IL-7 gene is flanked upstream and downstream with endogenous non-human regulatory sequences.

[0040] The genetically modified non-human animal is a rodent. In one embodiment, the rodent is selected from the group consisting of a mouse, a rat, and a hamster.

[0041] In one aspect, the genetically modified non-human animal described herein comprises a human exon selected from the group consisting of human exon 1, human exon 2, human exon 3, human exon 4, human exon 5, human exon 6, and a combination thereof. In one embodiment, the human or humanized IL-7 gene comprises at least five human exons.

[0042] In one aspect, a humanized IL-7 locus is described herein, comprising, a non-human exon 1, a human exon 2, a human exon 3, a human exon 4, a human exon 5 and a human exon 6. In some certain aspects, the humanized IL-7 locus further comprises 5' and 3' non-human untranslated regions flanking non-human exon 1 and human exon 6. In some certain embodiments, the humanized IL-7 locus comprises a 3' human untranslated region, or portion thereof, that is contiguous with a non-human 3' untranslated region. In some certain aspects, the humanized IL-7 locus comprises a 5' non-human untranslated region, or portion thereof, and non-human exon 1 that is contiguous with a human exon 2. In some certain aspects, a humanized IL-7 locus comprises the structure set forth in Figure 1.

[0043] In one aspect, a humanized IL-7 locus is described herein, comprising human exons 2-6 of a human IL-7 gene operably linked to non-human IL-7 regulatory sequences. In some certain aspects, a humanized IL-7 locus described herein comprises a non-human IL-7 exon 1. In some certain aspects, a humanized IL-7 locus described herein comprises a non-human IL-7 exon 1 and a non-human IL-7 intron 1. In some certain embodiments, a humanized IL-7 locus described herein comprises a 3' human IL-7 untranslated region, or portion thereof, that is contiguous with a non-human IL-7 3' untranslated region, or portion thereof. In some certain aspects, a humanized IL-7 locus described herein comprises a 5' non-human untranslated region, or portion thereof, and non-human exon 1 that is contiguous with a human IL-7 exon 2.

[0044] In one aspect, a humanized IL-7 locus is described herein, comprising a sequence that encodes an IL-7 protein that is substantially human. In some certain aspects, a humanized IL-7 locus comprises a sequence that is at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, or at least 98% identical to SEQ ID NO: 3. In some certain aspects, a humanized IL-7 locus comprises SEQ ID NO: 3. In some certain aspects, an IL-7 protein is encoded by a sequence that is at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, or at least 98% identical to SEQ ID NO: 3. In some certain aspects, an IL-7 protein is encoded by SEQ ID NO: 3.

[0045] In one aspect, a method is described herein for making a non-human animal with a human or humanized IL-7-encoding gene, comprising modifying the germline of the non-human animal to comprise a human or humanized IL-7-encoding gene flanked upstream and downstream with endogenous non-human IL-7 regulatory sequences.

[0046] In one aspect of the method, the modification is at an endogenous non-human IL-7 locus.

[0047] In one aspect of the method, the non-human animal is a rodent. In one aspect, the rodent is selected from the group consisting of a mouse, a rat, and a hamster.

[0048] In one aspect, a genetically modified non-human animal is described herein that is genetically modified to

express human IL-7 in an expression pattern that is the same expression pattern as observed for a wild-type non-human animal of the same genus and species. In one aspect, the non-human animal is a rodent. In a specific aspect, the rodent is selected from a mouse and a rat.

[0049] In one aspect, the level of human IL-7 expressed in the non-human animal is about the same as the level of non-human IL-7 in a corresponding wild-type mouse. In one aspect, the non-human animal is a rodent. In a specific aspect, the rodent is selected from a mouse and a rat.

[0050] In one aspect, a DNA construct is described herein, comprising from 5' to 3' with respect to direction of transcription, a nucleic acid sequence homologous to a mouse IL-7 5' noncoding sequence, a human genomic fragment encoding a human IL-7 protein but not comprising a human regulatory sequence upstream or downstream of sequence encoding the human IL-7 protein, and a nucleic acid sequence homologous to a mouse IL-7 3' noncoding sequence.

[0051] In one aspect, a DNA construct is described herein, comprising from 5' to 3' with respect to direction of transcription, a nucleic acid sequence that comprises a region of homology to a mouse IL-7 exon 1 sequence, a human genomic fragment encoding a human IL-7 protein but not comprising a human regulatory sequence upstream or downstream of sequence encoding the human IL-7 protein, and a nucleic acid sequence homologous to a mouse IL-7 3' noncoding sequence.

[0052] In one aspect, a genetically modified rodent is described herein, wherein the rodent comprises a DNA construct as described herein.

[0053] In one aspect, use of a DNA construct as described herein for making rodent or rodent cell that expresses a human IL-7 protein is described herein. In some certain aspects, the rodent or rodent cell does not detectably express a rodent IL-7 protein.

[0054] In one aspect, a genetically modified rodent cell is described herein, wherein the rodent cell comprises a replacement at an endogenous rodent IL-7 locus of a gene sequence encoding a rodent IL-7 with a human genomic sequence encoding a human IL-7. In some certain aspects, the replacement is made with DNA construct as described herein. In some certain aspects, the rodent cell is a rat cell. In some certain aspects, the rodent cell is a mouse cell.

[0055] In one aspect, the human genomic sequence comprises a contiguous human nucleic acid sequence spanning human IL-7 exons 2 through human IL-7 exon 6.

[0056] In one aspect, the genetically modified rodent comprises a mouse IL-7 promoter at the endogenous rodent IL-7 locus.

[0057] In one aspect, the cell is selected from a pluripotent cell, an induced pluripotent cell, a totipotent cell, an ES cell, and an ovum.

[0058] In one aspect, the cell secretes human IL-7. In one embodiment, the cell that secretes human IL-7 is selected from an epithelial cell (*e.g.*, an intestinal epithelial cell), a hepatocyte, a keratinocyte, a dendritic cell, and a follicular dendritic cell. In one aspect, the rodent cell is a bone marrow dendritic cell. In one aspect, the cell that secretes human IL-7 is a thymic stromal cell; in a specific aspect, the thymic stromal cell is a cortical epithelial cell.

[0059] In one aspect, a rodent embryo is described herein, wherein the embryo comprises at least one rodent donor cell (*e.g.*, an ES cell, a pluripotent cell, a totipotent cell, *etc.*) comprising a replacement of an endogenous rodent IL-7-encoding nucleic acid sequence with a nucleic acid sequence encoding a human IL-7 at the endogenous rodent IL-7 locus. In one aspect, the donor cell is a mouse ES cell and the embryo is a host mouse embryo that is a pre-morula, a morula, or a blastocyst.

[0060] In one aspect, a rodent tissue that comprises a humanized IL-7 gene at an endogenous rodent IL-7 locus is described herein, wherein the rodent tissue is selected from thymic, splenic, epidermal, and intestinal.

[0061] In one aspect, a genetically modified mouse is described herein that comprises a DNA sequence that encodes a human IL-7, wherein the mouse does not express a mouse IL-7, and wherein the mouse exhibits a T cell population that is about the same size as the T cell population of a wild-type mouse.

[0062] In one aspect, the mouse exhibits a peripheral T cell population that is about the same size as a peripheral T cell population of a wild-type mouse.

[0063] In one aspect, the T cell population is a mouse T cell population.

[0064] In one aspect, the mouse is not more prone than a wild-type mouse to develop a B cell tumor comprising a pro-B or a pre-B cell.

[0065] In one aspect, the mouse is not more prone than a wild-type mouse to develop a lymphoid tumor.

[0066] In one aspect, the mouse does not exhibit a lymphoproliferative disorder in the absence of a known lymphoproliferative causative agent.

[0067] In one aspect, the mouse does not exhibit a pathologic infiltration of T cell in a skin layer. In one embodiment, the mouse does not exhibit a symptom of alopecia.

[0068] In one aspect, the majority of T cells of the genetically modified mouse are about the same in size distribution as in an age-matched wild-type mouse. In a specific aspect, the genetically modified mouse does not exhibit an enlargement of T cell.

[0069] In one aspect, a rodent is provided that expresses a humanized or human IL-7 protein from an endogenous

modified rodent IL-7 locus, wherein the serum concentration of human IL-7 in the rodent is physiologically normal.

[0070] In one aspect, a humanized rodent is described herein that expresses a humanized IL-7 gene in the serum of the rodent at a physiologically normal concentration.

[0071] In one aspect, the rodent is selected from a mouse and a rat.

[0072] In one aspect, the physiologically normal serum concentration of human IL-7 is less than 10 picograms/mL. In one aspect, the physiologically normal serum concentration of human IL-7 is less than 5 picograms/mL. In one aspect, the physiologically normal serum concentration of human IL-7 in the rodent is about 2 picograms/mL to about 4 picograms/mL. In one aspect, the physiologically normal serum concentration of human IL-7 in the rodent serum is about 2.4 picograms/mL to about 3.2 picograms/mL.

[0073] In one aspect, a method for making a human IL-7 protein is described herein, comprising inserting into the germline of the non-human animal a human or humanized IL-7 coding gene under control of endogenous non-human regulatory elements, allowing the non-human animal to make the human or humanized IL-7, and isolating from the non-human animal (e.g., a mammal, e.g., a rodent such as, e.g., a mouse or rat or hamster) human or humanized IL-7.

[0074] In one aspect, a method for making a human IL-7 protein is described herein, comprising isolating from a non-human animal as described herein (e.g., a mammal, e.g., a rodent such as, e.g., a mouse or rat or hamster).

[0075] In one aspect, a method is described herein for making a non-human animal that comprises a human or humanized IL-7 gene in its germline, comprising inserting into the germline of the non-human animal a human or humanized IL-7-encoding nucleic acid sequence or fragment thereof, wherein the human or humanized IL-7-coding nucleic acid sequence or fragment thereof is under regulatory control of endogenous non-human regulatory elements. In one aspect, the human or humanized IL-7 gene is at an endogenous non-human IL-7 locus (i.e., inserted between upstream and downstream non-human regulatory elements at the endogenous non-human IL-7 locus, wherein the human or humanized IL-7-coding nucleic acid sequence replaces the wild-type existing non-human IL-7 coding sequence in whole or in part). In one aspect, the non-human animal is a mammal, e.g., rodent. In one aspect, the rodent is selected from a mouse, a rat, and a hamster.

[0076] In one aspect, a method for making a non-human animal that comprises a human or humanized IL-7 gene is described herein, comprising inserting a DNA construct comprising exons 2- 6 of a human IL-7 gene into an endogenous non-human IL-7 gene of a non-human cell.

[0077] In one aspect, a method is described herein for isolating from a non-human animal a T cell that has been exposed to a human or humanized IL-7 protein, comprising a step of isolating a T cell from a non-human animal as described herein. In one aspect, the non-human animal is a mouse or a rat. In one aspect, the T cell is a non-human T cell, e.g., a rodent T cell, e.g., a T cell of a mouse or a rat. In one aspect, the T cell is selected from a T cell in the thymus and a peripheral T cell.

[0078] In one aspect, a method for identifying an agent that is an antagonist of human IL-7 is described herein, comprising a step of administering an agent to a genetically modified rodent as described herein, determining an effect of the agent on a human IL-7-mediated function in the rodent, and identifying the agent as an IL-7 antagonist if it antagonizes the function of human IL-7 in the genetically modified rodent.

[0079] In one aspect, use of a genetically modified rodent as described herein for identifying an agent that is an antagonist of human IL-7 is described herein, comprising of administering an agent to the genetically modified rodent, determining an effect of the agent on a human IL-7-mediated function in the rodent, and identifying the agent as an IL-7 antagonist if it antagonizes the function of human IL-7 in the genetically modified rodent.

[0080] In one aspect, the agent comprises an immunoglobulin variable domain that binds IL-7. In one aspect, the agent specifically binds human IL-7 but not rodent IL-7. In one embodiment, the agent is an antibody.

[0081] In one aspect, a method for determining whether an agent reduces IL-7-mediated peripheral T cell population is described herein, comprising a step of administering to a genetically modified rodent as described herein an IL-7 antagonist for a period of time, measuring peripheral T cell population number of the rodent at one or more time periods following administration, and determining whether the IL-7 antagonist reduces the peripheral T cell population.

[0082] In one aspect, use of a genetically modified rodent as described herein for determining whether an agent reduces IL-7-mediated peripheral T cell population is described herein, comprising administering to the genetically modified rodent an IL-7 antagonist for a period of time, measuring peripheral T cell population number of the rodent at one or more time periods following administration, and determining whether the IL-7 antagonist reduces the peripheral T cell population.

[0083] In one aspect, the genetically modified non-human animal is heterozygous for a human or humanized IL-7-encoding gene. In one aspect, the non-human animal is unable to express an endogenous IL-7 protein. In a specific aspect, the non-human animal comprises a knockout of both endogenous IL-7 alleles.

[0084] Each of the aspects and embodiments described above and below may be used together, unless otherwise stated and unless otherwise clear from the context.

BRIEF DESCRIPTION OF THE FIGURES

[0085]

Figure 1 depicts (not to scale) a schematic of a wild-type mouse IL7 gene locus (top) and a humanized endogenous mouse IL-7 locus (bottom). Open symbols indicate human sequence; closed symbols indicate mouse sequence; shaded items indicate untranslated regions; stippled region indicates other sequence.

Figure 2 depicts human IL-7 concentration in serum of wild-type mice that has a genetic background of 75% C57B6 and 25% 129/SvJ (75/25 WT) and mice heterozygous for a humanized endogenous IL-7 locus as described herein (5148 Het).

DETAILED DESCRIPTION

[0086] In various aspects, non-human animals are described that comprise the genetic modification(s) described herein. The genetically modified non-human animal may be selected from a group consisting of a mouse, rat, rabbit, pig, bovine (e.g., cow, bull, buffalo), deer, sheep, goat, chicken, cat, dog, ferret, primate (e.g., marmoset, rhesus monkey). For the non-human animals where suitable genetically modifiable ES cells are not readily available, other methods are employed to make a non-human animal comprising the genetic modification. Such methods include, e.g., modifying a non-ES cell genome (e.g., a fibroblast or an induced pluripotent cell) and employing nuclear transfer to transfer the modified genome to a suitable cell, e.g., an oocyte, and gestating the modified cell (e.g., the modified oocyte) in a non-human animal under suitable conditions to form an embryo.

[0087] In one aspect, the non-human animal is a mammal. In one aspect, the non-human animal is a small mammal, e.g., of the superfamily *Dipodoidea* or *Muroidea*. According to the invention, the genetically modified animal is a rodent, i.e. a genetically modified rodent as defined by the claims. In one embodiment, the rodent is selected from a mouse, a rat, and a hamster. In one embodiment, the rodent is selected from the superfamily *Muroidea*. In one embodiment, the genetically modified animal is from a family selected from *Calomyscidae* (e.g., mouse-like hamsters), *Cricetidae* (e.g., hamster, New World rats and mice, voles), *Muridae* (true mice and rats, gerbils, spiny mice, crested rats), *Nesomyidae* (climbing mice, rock mice, with-tailed rats, Malagasy rats and mice), *Platacanthomyidae* (e.g., spiny dormice), and *Spalacidae* (e.g., mole rates, bamboo rats, and zokors). In a specific embodiment, the genetically modified rodent is selected from a true mouse or rat (family *Muridae*), a gerbil, a spiny mouse, and a crested rat. In one embodiment, the genetically modified mouse is from a member of the family *Muridae*. In one embodiment, the animal is a rodent. In a specific embodiment, the rodent is selected from a mouse and a rat. In one embodiment, the non-human animal is a mouse.

[0088] In various embodiments, the rodent is a mouse of a C57BL strain selected from C57BL/A, C57BL/An, C57BL/GrFa, C57BL/KaLwN, C57BL/6, C57BL/6J, C57BL/6ByJ, C57BL/6NJ, C57BL/10, C57BL/10ScSn, C57BL/10Cr, and C57BL/O1a. In another embodiment, the mouse is a 129 strain selected from the group consisting of a strain that is 129P1, 129P2, 129P3, 129X1, 129S1 (e.g., 129S1/SV, 129S1/SvIm), 129S2, 129S4, 129S5, 129S9/SvEvH, 129S6 (129/SvEvTac), 129S7, 129S8, 129T1, 129T2 (see, e.g., Festing et al. (1999) Revised nomenclature for strain 129 mice, Mammalian Genome 10:836, see also, Auerbach et al (2000) Establishment and Chimera Analysis of 129/SvEv- and C57BL/6-Derived Mouse Embryonic Stem Cell Lines). In a specific embodiment, the genetically modified mouse is a mix of an aforementioned 129 strain and an aforementioned C57BL/6 strain. In another specific embodiment, the mouse is a mix of aforementioned 129 strains, or a mix of aforementioned BL/6 strains. In a specific embodiment, the 129 strain of the mix is a 129S6 (129/SvEvTac) strain. In another embodiment, the mouse is a BALB strain, e.g., BALB/c strain. In one embodiment, the mouse is a mix of a BALB strain and another aforementioned strain.

[0089] In one embodiment, the rodent is a rat. In one embodiment, the rat is selected from a Wistar rat, an LEA strain, a Sprague Dawley strain, a Fischer strain, F344, F6, and Dark Agouti. In one embodiment, the rat strain is a mix of two or more strains selected from the group consisting of Wistar, LEA, Sprague Dawley, Fischer, F344, F6, and Dark Agouti.

[0090] Genetically modified non-human animals that comprise a replacement of a non-human IL-7 gene sequence with a human IL-7 gene sequence are described herein. Rodents that comprise a humanization of an IL-7 gene, at an endogenous rodent IL-7 locus, are described herein. Methods for making rodents, e.g., mice, that comprise a replacement of an endogenous IL-7 gene or fragment thereof (e.g., a fragment comprising one or more exons) with a humanized IL-7 gene, or fragment thereof (e.g., a fragment comprising one or more exons), at the endogenous IL-7 locus. Cells, tissues, and mice are described herein that comprise the humanized gene, as well as cells, tissues, and mice that express human IL-7 from an endogenous non-human IL-7 locus. Exemplary flanking genomic sequences of a humanized IL-7 gene are provided in SEQ ID NO: 1 (5' flanking sequence) and SEQ ID NO: 2 (3' flanking sequence). An exemplary human IL-7 gene is provided in SEQ ID NO: 3.

[0091] IL-7 is a cytokine that is essential for development of immature B and T cells and, to some degree, mature T cells; IL-7 knockout mice display a severe depletion of mature B and T cells (von Freeden-Jeffry U. et al. (1995) Lymphopenia in interleukin (IL)-7 gene-deleted mice identifies IL-7 as a nonredundant cytokine, J. Exp. Med. 181:1519-1526).

The depletion is apparently due to a block between pro-B and pre-B cells, and a block in T cell proliferation (rather than a block in T cell differentiation; ratios of T cell types in IL-7 KO mice are about normal) that results in a depressed population of T cells and mature B cells (*Id.*). IL-7 is produced by epithelial cells in the thymus and intestine, in keratinocytes, liver, and dendritic cells-but not by normal lymphocytes (reviewed, *e.g.*, in Fry T.J. and Mackall, C.L. (2002) Interleukin-7: from bench to clinic, *Blood* 99(11):3892-3904).

[0092] Simply put, IL-7 increases T cell number and enhances T cell function (see, *e.g.*, Morrissey, J.J. (1991) Administration of IL-7 to normal mice stimulates B-lymphopoiesis and peripheral lymphadenopathy, *J. Immunol.* 147:561-568; Faltynek, C.R. et al. (1992) Administration of human recombinant IL-7 to normal and irradiated mice increases the numbers of lymphocytes and some immature cells of the myeloid lineage, *J. Immunol.* 149:1276-1282; Risdon, G.J. et al. (1994) Proliferative and cytotoxic responses of human cord blood T lymphocytes following allogenic stimulation, *Cell. Immunol.* 154:14-24). Functional enhancement of T cells can be achieved by a short duration of IL-7 exposure, whereas increases in T cell number reflect a proliferative effect that is achieved with a longer duration exposure (Geiselhart, L.A. et al. (2001) IL-7 Administration Alters the CD4:CD8 Ratio Increases T Cell Numbers, and Increases T Cell Function in the Absence of Activation, *J. Immunol.* 166:3019- 3027; see also, Tan J.T. et al. (2001) IL-7 is critical for homeostatic proliferation and survival of naïve T cells, *Proc. Natl. Acad. Sci. USA* 98(15):8732-8737).

[0093] IL-7 is necessary for both early and late stage T cell regulation. IL-7 is not expressed by T cells, which must encounter IL-7 that is released by non-thymic cells in the periphery and that is believed to be responsible for peripheral T cell proliferation and maintenance (reviewed, *e.g.*, in Guimond, M (2005) Cytokine Signals in T-Cell Homeostasis, *J. Immunother.* 28(4):289-294). IL-7 starvation results in severely impaired T cell development and survival of naïve T cells. IL-7 also appears to be necessary for the survival of mature T cells; mature T cells acquired through adoptive transfer into IL-7-deficient mice enter apoptosis where the mice lack an IL-7 gene, but not in mice that express IL-7 that lack an IL-7R gene (Schluns, K.S. et al. (2000) Interleukin-7 mediates the homeostasis of naive and memory CDS T cells in vivo, *Nat. Immunol.* 1(5):426-432. Loss of IL-7 function results in a SCID-like phenotype in mice (Puel, A. and Leonard, W J. (2000) Mutations in the gene for the IL-7 receptor result in T(-)B(+)NK(+) severe combined immunodeficiency disease, *Curr. Opin. Immunol.* 12:468-473), presumably due to T cell atrophy and death caused by diminished growth rate likely mediated by glycolytic insufficiency in the absence of IL-7 stimulus (Jacobs, S.R. et al. (2010) IL-7 Is Essential for Homeostatic Control of T Cell Metabolism In Vivo, *J. Immunol.* 184:3461-3469).

[0094] The human IL-7 gene comprises 6 exons that extend over 33 kb and is located on chromosome 8 at 8q12-13. Mouse IL-7 comprises 5 exons (there is no counterpart in mouse to human exon 5) and is about 80% homologous to the human gene; analysis of non-coding sequences of the human and the mouse genes revealed a paucity of recognizable regulatory motifs responsible for transcription and regulation of gene expression (Lupton, S.D. et al. (1990) Characterization of the Human and Murine IL-7 Genes, *J. Immunol.* 144(9):3592-3601), suggesting that regulation of IL-7 expression may be complex. However, mouse BAC fragments comprising a reporter gene at the hIL-7 locus have been expressed in mice to successfully ascertain expression patterns of IL-7 in mice (see, *e.g.*, Avles, N.L. et al. (2009) Characterization of the thymic IL-7 niche in vivo, *Proc. Natl. Acad. Sci. USA* 106(5):1512- 1517; Mazzucchelli, R.I. (2009) Visualization and Identification of IL-7 Producing Cells in Reporter Mice, *PLoS ONE* 4(11):e7637; Repas, J.F. et al. (2009) IL7-hCD25 and IL7-Cre BAC transgenic mouse lines: new tools for analysis of IL-7 expressing cells, *Genesis* 47:281-287). In at least one case, a BAC-based replacement of an IL-7 exon with a reporter required the entire 43 kb IL-7 locus as well as 96 kb of 5' flanking sequence and 17 kb of 3' flanking sequence in the hope of faithfully recapitulating IL-7 expression of wild-type mice (Repass, J.F. et al. (2009)). In any case, data from the different studies on reporter expression driven by putative IL-7 regulatory elements vary somewhat from one another and from earlier observations, supporting an inference that IL-7 regulation might not have been faithfully recapitulated in these reporter mice (IL-7 reporter transgenic mice are reviewed in Kim, G.Y. et al. (2011) Seeing Is Believing: Illuminating the Source of In Vivo Interleukin-7, *Immune Network* 11(1): 1-10). Human IL-7 is functional on mouse cells, but mouse IL-7 is not functional on human cells.

[0095] Transgenic mice that express abnormally or poorly regulated human IL-7 exhibit a panoply of pathologies or syndromes. Mice transgenic for a murine IL-7 cDNA under control of mouse Ig heavy chain enhancer, κ light chain enhancer, and light chain promoter) to target expression in the lymphoid compartment) exhibit significantly enhanced numbers of B cell precursors and an overall expansion of all subsets of thymocytes in the thymus and peripheral T cells (Samaridis, J. et al. (1991) Development of lymphocytes in interleukin 7-transgenic mice, *Eur. J. Immunol.* 21:453-460).

[0096] Transgenic mice that express IL-7 from a mouse cDNA under control of an SR α promoter develop a panoply of pathologies, including a chronic colitis that histopathologically mimics chronic colitis in humans, and is characterized by at least a transient over-expression of IL-7 in colonic mucosal lymphocytes (but not colonic epithelial cells) and its apparent accumulation in mucus of goblet cells of the colonic mucosa (Watanabe, M. et al. (1998) Interleukin 7 Transgenic Mice Develop Chronic Colitis with Decreased Interleukin 7 Protein Accumulation in the Colonic Mucosa, *J. Exp Med.* 187(3):389-402; Takebe, Y. et al. (1988) sR alpha promoter: an efficient and versatile mammalian cDNA expression system composed of the simian virus 40 early promoter and the R-U5 segment of human T-cell leukemia virus type 1 long terminal repeat, *Mol. Cell Biol.* 8(1):466-472). Constitutive expression of mouse IL-7 driven by the same promoter in transgenic mice also develop a severe dermatitis characterized by gross deformities and a massive dermal infiltration

of mononuclear cells that are mostly TCR $\gamma\delta$ cells (Uehira, M. et al. The development of dermatitis infiltrated by $\gamma\delta$ T cells in IL-7 transgenic mice, *Int. Immunol.* 5(12): 1619-1627). Transgenic mice expressing a murine IL-7 cDNA driven by a murine heavy chain promoter and enhancer also exhibited dermatitis and lymphoproliferation into the dermis, but reportedly of TCR $\alpha\beta$ cells and cells that express Thy-1, CD3, and CD5 but lack CD4 and CD8 (CD4⁺/CD8⁺ thymocytes are virtually absent from these transgenic mice); these mice also developed B and T cell lymphomas, presumably associated with a prolonged lymphoproliferation observed in these mice (see, Rich, B.E. et al. (1993) Cutaneous lymphoproliferation and lymphomas in interleukin 7 transgenic mice, *J. Exp. Med.* 177:305-316).

[0097] Dysregulation of the IL-7 gene is associated with a variety of pathological states. Mice expressing transgenic mouse IL-7 under control of the MHC class II E α promoter are highly prone to lymphoid tumors (see, e.g., Fisher, A.G. et al. (1995) Lymphoproliferative disorders in IL-7 transgenic mice: expansion of immature B cells which retain macrophage potential, *Int. Immunol.* 7(3):414-423; see, also, Ceredig, R. et al. (1999) Effect of deregulated IL-7 transgene expression on B lymphocyte development in mice expressing mutated pre-B cell receptors, *Eur. J. Immunol.* 29(9):2797-2807). T cell sizes are also larger in the transgenic mice, and a polyclonal T cell expansion is observed (predominantly CD8⁺, indicating a perturbed regulation in these mice) (Mertsching, E. et al. IL-7 transgenic mice: analysis of the role of IL-7 in the differentiation of thymocytes *in vivo* and *in vitro*, *Int. Immunol.* 7(3):401-414). Other transgenic mice that over-express mIL-7 (by about 25-50-fold) through the MHC class II E α promoter appear grossly healthy (but for a low incidence of B cell tumors) and exhibit a 10-20-fold increase in T cell number over wild-type mice, characterized by large numbers of CD8⁺ cells that are also CD44^{hi} and CD122^{hi} (Kieper W.C. et al. (2002) Overexpression of Interleukin(IL)-7 Leads to IL-15-independent Generation of Memory Phenotype CD8⁺ T Cells, *J. Exp.Med.* 195(12):1533-1539).

[0098] Mice that constitutively express mouse IL-7 from a cDNA under control of the MHC class II E α promoter selectively expand IL-7-responsive early B cells, and are a good source of tumors comprising pro-B and pre-B cells. Mice that express IL-7 driven by a human K14 promoter develop a lymphoproliferative response that results in T cell infiltrates of skin that resemble alopecia.

[0099] Mice transgenic for IL-7R display large reductions in double negative (CD4⁻ CD8⁻) precursor cells in thymus, presumably due to depletion of IL-7 by the large number of double positive thymocytes in the transgenic mice, suggesting that IL-7 levels must be exquisitely controlled to promote normal thymocyte development (see, e.g., Malek, T.R. (2004) IL-7: a limited resource during thymopoiesis, *Blood*, 104(13):2842).

[0100] As early as the cloning of human IL-7, it has been known that human IL-7 can induce proliferation of murine pre-B cells (Goodwin, R.G. et al. (1989) Human interleukin 7: Molecular cloning and growth factor activity on human and murine B-lineage lines, *Proc. Natl. Acad. Sci. USA* 86:302-306). Although expressed in certain chronic lymphocytic leukemia cells, expression of mouse IL-7 in tumor cells implanted in mice induce inflammation and reduced tumorigenicity, yet paradoxically mice transgenic for IL-7 are prone to lymphomas (reviewed in Foss, H.-D. et al (1995) Frequent Expression of IL-7 Gene Transcripts in Tumor Cells of Classical Hodgkin's Disease, *Am. J. Pathol.* 146(1):33-39). Thus, it is desirable to obtain mice that express human IL-7 (but not mouse IL-7) from endogenous mouse IL-7 loci in a physiologically relevant fashion, in particular but not limited to mice that comprise human or mouse tumors, e.g., lymphocytic tumors.

[0101] Mice that express human IL-7 in a physiologically relevant manner are also useful for evaluating anti-tumor properties of putative therapeutics (including human IL-7 and analogs thereof) in xenograft models of human solid tumors in mice. For example, SCID mice implanted with HT29 human colon adenocarcinoma and tested under a variety of conditions (e.g., ablation of native T cells and addition of human T cells; addition of recombinant human IL-7, etc.) (see, Murphy, W.J. et al. (1993) Antitumor Effects of Interleukin-7 and Adoptive Immunotherapy on Human Colon Carcinoma Xenografts, *J. Clin. Invest.* 92:1918-1924). That study found that human IL-7 when administered with human T cells resulted in a significantly prolonged survival than in the absence of human IL-7 (*Id.*).

[0102] Thus, mice that express human IL-7, in particular mice that are capable of supporting a xenograft (e.g., a human tumor), such as, e.g., immunodeficient mice, have a specific and a well-established utility. IL-7 signaling has been shown to be necessary for development and survival of human T-cell acute lymphoblastic leukemias (T-ALL) *in vitro* and *in vivo*. (Touw, 1. et al. (1990) Interleukin-7 is a growth factor of precursor B and T acute lymphoblastic leukemia. *Blood* 75, 2097-2101) T-ALL is an aggressive hematological cancer with poor prognosis; the understanding of mechanisms driving proliferation and survival of T- ALL cells remains relatively poor due to lack of xenograft models that can support the growth of patient derived tumors *in vivo*. Thus, an immunodeficient animal expressing human IL-7 can serve as an *invaluable in vivo* system for testing pharmaceutical compositions against such T- cell related malignancies, e.g., testing the efficacy of a pharmaceutical composition to target IL-7-mediated signaling in a mouse that expresses human IL-7 and has an implanted T-cell derived tumor, wherein the tumor requires IL-7 signaling for development and survival.

EXAMPLES

Example 1. Humanizing the Mouse IL-7 Locus

[0103] Mouse ES cells were modified to replace mouse IL-7 gene sequences with human IL-7 gene sequences at the endogenous mouse IL-7 locus, under control of mouse IL-7 regulatory elements, using VELOCIGENE® genetic engineering technology, to produce a humanized locus as shown in FIG. 1.

[0104] Targeting Construct. Bacterial homologous recombination (BHR) is performed to construct a large targeting vector (LTVEC) containing the human IL-7 gene for targeting to the mouse IL-7 locus using standard BHR techniques (see, e.g., Valenzuela et al. (2003) High-throughput engineering of the mouse genome coupled with high-resolution expression analysis, *Nature Biotech.* 21(6):652-659). Linear fragments are generated by ligating PCR-generated homology boxes to cloned cassettes followed by gel isolation of ligation products and electroporation into BHR-competent bacteria harboring the target bacterial artificial chromosome (BAC). Mouse BAC bMQ-271g18 is used as the source of mouse sequence; human BAC RP11-625K1 is used as the source of human sequence, following a selection step, correctly recombined clones are identified by PCR across novel junctions, and by restriction analysis. A large targeting vector (LTVEC) containing the homology arms and human IL-7 gene sequences was made. Mouse ES cells were electroporated with the LTVEC constructs, grown on selection medium, and used as donor ES cells to make humanized IL-7 mice.

[0105] The mouse IL-7 gene (mouse Gene ID: 96561; Ref Seq transcript: NM_008371.4) is modified by deleting exons 2 through 5 (deletion coordinates NCBI37:ch3:7604650-7573021; minus strand) and replacing them with human IL-7 (Entrez Gene ID: 6023; Ref Seq transcript NM_000880.3) exons 2 through 6 (replacement coordinates GRCh37Lch*:79711168-79644608; minus strand). The human genomic IL-7 sequence is provided in SEQ ID NO: 3 (NC#166E2F2). The mouse genomic IL-7 locus is known and reported as a 41,351 nt sequence under accession number NC0000696; relevant 5' and 3' sequences of the mouse IL-7 genomic locus are provided in SEQ ID NO:1 (5' flanking) and SEQ ID NO:2 (3' flanking).

[0106] The LTVEC comprising the humanized IL-7 gene had a 48 kb upstream mouse targeting arm flanked upstream with a NotI site, and a 77 kb downstream mouse targeting arm flanked downstream with a NotI site. The LTVEC was linearized with NotI for electroporation.

[0107] Following construction of the LTVEC, nucleotide sequence of the LTVEC was obtained across the mouse/human 5' junction, which included, from 5' (mouse) to 3' (human), the following sequence with the mouse/human junction nucleotides in parenthesis: 5' - TGCAAGCACC AAAAAGGTGA CCACACTTCA CATTGGCGAT CGC(GG)GTTTC TATCTGAGGA TGTGAATTTA TTTACAGA - 3' (SEQ ID NO: 4).

[0108] Nucleotide sequence of the LTVEC across the junction of the human insertion and the 5' end of the cassette (see FIG. 1) was determined and included the following sequence having, from 5' to 3', human sequence/restriction site/loxP/cassette sequence with the human sequence/restriction site junction nucleotides in parenthesis: 5' - GTTATGTGCT GATGGGCTTT ATTTGATCTA CAGAAGATGC TCTGGTGACA CCCTCAGTGT GTGTTGGTAA CACCTTCCTG (CC)TCGAGATA ACTTCGTATA ATGTATGCTA TACGAAGTTA TATGCATGGC CTCCGCGCCG GGTTTTGGCG CC - 3' (SEQ ID NO: 5).

[0109] Nucleotide sequence of the LTVEC across the junction of the end of the cassette and the beginning of mouse sequence was determined and included the following sequence having, from 5' to 3', cassette sequence/restriction site/mouse sequence with the junction nucleotides in parenthesis: 5' - GTATGCTATA CGAAGTTATG CTAGTAACTA TAACGGTCCT AAGGTAGCGA GCTAG(CC)CAA TTGCGTACTT TGGATAGTGT CTCTTTTAA CCTAAATGAC CTTTATTAAC ACTGTCAGGT TCCCTTACTC TCGAGAGTGT TCATTGCTGC ACT - 3' (SEQ ID NO: 6).

[0110] Following electroporation of the ES cell, a loss of native allele assay (see, e.g., Valenzuela et al. (2003)) is performed to detect loss of endogenous IL-7 sequence due to the targeting. Primer pairs, fragment sizes, and TAQMAN™ probes are as shown in Table 1. The C1 probe binds the mouse IL-7 genomic sequence (NC0000696) at nts 9,635-9,664; the C2 probe binds the mouse IL-7 genomic sequence (NC0000696) at nts 39,793-39,825. For a gain of allele assay, the C3 probe binds the human IL-7 genomic sequence (NC#166E2F2) at nts 29,214-29,242.

TABLE 1, LTVEC Primers and Probes

Primer		Sequence (5' to 3')	Size (bp)
Primer Pair	Forward	TTGCATTCTT TTCCAAATAA GTGG (SEQ ID NO: 7)	
C1	Reverse	TTCCAGGATG AATAGGATAA ACAGG (SEQ ID NO: 8)	81
C1 TAQMAN™	probe	ATCCATCATC ACTCCCTGTG TTTGTTTCCC (SEQ ID NO: 9)	
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Example 2. Humanized IL-7 Mice

[0111] Generating humanized IL-7 mice. Donor mouse ES cells comprising a humanized IL-7 locus are introduced into early stage mouse embryos by the VELOCIMOUSE® method (Poueymirou et al. (2007) F0 generation mice fully derived from gene-targeted embryonic stem cells allowing immediate phenotypic analyses, NatBiotechnol 25:91-99). Four F0 mice fully derived from donor ES cells were obtained that were heterozygous for humanization of the endogenous mouse IL-7 locus. F0 mice are bred to homozygosity with respect to the humanization. Homozygous mice are genotyped to confirm homozygosity. All mouse studies were overseen and approved by Regeneron's Institutional Animal Care and Use Committee (IACUC).

Example 3. Expression of Human IL -7 in a Mouse

[0112] Mice humanized for the IL- 7 gene and their non-humanized littermate controls were bled and serum concentrations of human IL-7 were measured using QuantikineHS Human IL -7 Immunoassay kit from R&D Systems, Inc. Data was analyzed using Microsoft Excel and plotted using Prism statistical analysis software. Mice heterozygous for the humanized IL-7 locus (designated MAID 5148 het) expressed human IL-7 in serum at a physiologically relevant concentration. This is in contrast to transgenic human IL-7 mice bearing lentivirally transduced human IL-7 in double knockout mice, which mice exhibit unphysiologically and potentially seriously detrimental high levels of human IL-7 in serum (10 to 100 pg/ mL) (O'Connell, R. M. *et al.* (2010) Lentiviral Vector Delivery of Human Interleukin-7 ((hIL- 7) to Human Immune System (HIS) Mice Expands T Lymphocyte Populations, PLoS ONE 5(8): e12009). In contrast, mice heterozygous for a humanized endogenous IL-7 locus exhibited about 2.4 to about 3.2 pg/mL in serum (FIG. 2), reflecting normal, or physiologically appropriate, levels of IL-7.

SEQUENCE LISTING

[0113]

<110> Regeneron Pharmaceuticals, Inc.

<120> Humanized IL-7 Rodents

<130> 2010794-0291

<150> US 61/660,976

<151> 2012-06-18

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Claims

1. A genetically modified rodent comprising in its germline a replacement of rodent IL-7 exons 2 through 5 with human IL-7 exons 2 through 6 to form a human or humanized IL-7-encoding gene, wherein the replacement is at an endogenous rodent IL-7 locus, wherein the human or humanized IL-7-encoding gene is under control of endogenous rodent IL-7 regulatory elements.
2. The genetically modified rodent of claim 1, which is selected from the group consisting of a rat, a mouse and a hamster.
3. The genetically modified rodent of claim 1 or 2, wherein the human or humanized IL-7-encoding gene comprises no more than five human exons.
4. The genetically modified rodent of claim 1, wherein the rodent is a mouse and the modified locus comprises a replacement of mouse exons 2, 3, 4, and 5 with a human genomic segment comprising human IL-7 exons 2, 3, 4, 5, and 6.
5. The genetically modified rodent of claim 1, wherein the human or humanized IL-7-encoding gene comprises a cDNA encoding a human or humanized IL-7 protein.
6. The genetically modified rodent of any of the preceding claims, wherein the human or humanized IL-7 is expressed in an expression pattern that is the same expression pattern as observed for a wild-type rodent of the same species.
7. The genetically modified rodent of claim 6, wherein the level of the human or humanized IL-7 expressed in the rodent is about the same as the level of rodent IL-7 in a corresponding wild-type rodent.
8. A method for making a rodent with a human or humanized IL-7-encoding gene, comprising modifying the germline of the rodent by replacement of rodent IL-7 exons 2 through 5 with human IL-7 exons 2 through 6 to form a human or humanized IL-7-encoding gene flanked upstream and downstream with endogenous rodent IL-7 regulatory sequences, wherein the modification is at an endogenous rodent IL-7 locus.
9. The method of claim 8, wherein the rodent is selected from the group consisting of a mouse, a rat, and a hamster.
10. A humanized IL-7 locus comprising a rodent IL-7 exon 1, a human IL-7 exon 2, a human IL-7 exon 3, a human IL-7 exon 4, a human IL-7 exon 5 and a human IL-7 exon 6, wherein the humanized IL-7 locus optionally further comprises 5' and 3' rodent IL-7 untranslated regions flanking the rodent IL-7 exon 1 and human IL-7 exon 6, and wherein the humanized IL-7 locus optionally also further comprises a 3' human untranslated region, or portion thereof, that is contiguous with a rodent 3' untranslated region.
11. A cell comprising a humanized IL-7 locus of claim 10.
12. The cell of claim 11, which is an embryonic stem cell.
13. A tissue isolated from a rodent of any one of claims 1-7, comprising a replacement at an endogenous rodent IL-7 locus as defined in any one of claims 1-7.
14. The tissue of claim 13, which is selected from the group consisting of thymic, splenic, epidermal, and intestinal.

Patentansprüche

1. Genetisch modifizierter Nager, umfassend in seiner Keimbahn einen Ersatz der Nager-IL-7-Exons 2 bis 5 mit humanen IL-7-Exons 2 bis 6, um ein humanes oder humanisiertes IL-7-kodierendes Gen zu bilden, wobei sich der Ersatz an einem endogenen Nager-IL-7-Lokus befindet, wobei das humane oder humanisierte IL-7-kodierende Gen sich unter der Kontrolle von endogenen regulatorischen Elementen von Nager-IL-7 befindet.
2. Genetisch modifizierter Nager nach Anspruch 1, welcher ausgewählt ist aus der Gruppe bestehend aus einer Ratte, einer Maus und einem Hamster.

3. Genetisch modifizierter Nager nach Anspruch 1 oder 2, wobei das humane oder humanisierte IL-7-kodierende Gen nicht mehr als fünf humane Exons umfasst.
4. Genetisch modifizierter Nager nach Anspruch 1, wobei der Nager eine Maus ist und der modifizierte Locus einen Ersatz der Mausexons 2, 3, 4 und 5 mit einem humanen genomischen Segment umfassend die humanen IL-7-Exons 2, 3, 4, 5 und 6 umfasst.
5. Genetisch modifizierter Nager nach Anspruch 1, wobei das humane oder humanisierte IL-7-kodierende Gen eine cDNA umfasst, die ein humanes oder humanisiertes IL-7-Protein kodiert.
6. Genetisch modifizierter Nager nach einem der vorherigen Ansprüche, wobei das humane oder humanisierte IL-7 in einem Expressionsmuster exprimiert wird, welches das gleiche Expressionsmuster ist, welches für einen Wildtyp-Nager der gleichen Gattung beobachtet wird.
7. Genetisch modifizierter Nager nach Anspruch 6, wobei das Niveau des in dem Nager exprimierten humanen oder humanisierten IL-7 in etwa das gleiche ist, wie das Niveau von Nager-IL-7 in einem entsprechenden Wildtyp-Nager.
8. Verfahren zum Erzeugen eines Nagers mit einem humanisierten oder humanisierten IL-7-kodierenden Gen, umfassend ein Modifizieren der Keimbahn des Nagers durch einen Ersatz der Nager-IL-7-Exons 2 bis 5 mit humanen IL-7-Exons 2 bis 6, um ein humanes oder humanisiertes IL-7-kodierendes Gen zu bilden, welches stromaufwärts und stromabwärts mit regulatorischen Sequenzen von endogenem Nager-IL-7 flankiert ist, wobei die Modifikation sich an einem endogenen Nager-IL-7-Lokus befindet.
9. Verfahren nach Anspruch 8, wobei der Nager ausgewählt ist aus der Gruppe bestehend aus einem Maus, einer Ratte und einem Hamster.
10. Humanisierter IL-7-Lokus, umfassend ein Nager-IL-7-Exon 1, ein humanes IL-7-Exon 2, ein humanes IL-7-Exon 3, ein humanes IL-7-Exon 4, ein humanes IL-7-Exon 5 und ein humanes IL-7-Exon 6, wobei der humanisierte IL-7-Lokus gegebenenfalls ferner 5'- und 3'-untranslatierte Nager-IL-7-Regionen umfasst, welche das Nager-IL-7-Exon 1 und humane IL-7-Exon 6 flankieren, und wobei der humanisierte IL-7-Lokus gegebenenfalls ferner auch eine 3'-untranslatierte humane Region oder einen Abschnitt davon umfasst, die an eine 3'-untranslatierte Nagerregion grenzt.
11. Zelle umfassend einen humanisierten IL-7-Lokus nach Anspruch 10.
12. Zelle nach Anspruch 11, welche eine embryonale Stammzelle ist.
13. Gewebe isoliert aus einem Nager nach einem der Ansprüche 1 - 7, umfassend einen Ersatz an einem endogenen Nager-IL-7-Lokus nach einem der Ansprüche 1 - 7.
14. Gewebe nach Anspruch 13, welches ausgewählt ist aus der Gruppe bestehend aus thymisch, splenisch, epidermal und intestinal.

Revendications

1. Rongeur modifié génétiquement comprenant dans sa lignée germinale un remplacement des exons 2 à 5 de l'IL-7 de rongeur par les exons 2 à 6 de l'IL-7 humaine pour former un gène codant pour l'IL-7 humaine ou humanisée, où le remplacement est situé à un locus d'IL-7 endogène de rongeur, où le gène codant pour l'IL-7 humaine ou humanisée est sous le contrôle d'éléments régulateurs d'IL-7 endogène de rongeur.
2. Rongeur modifié génétiquement selon la revendication 1, qui est choisi dans le groupe constitué d'un rat, d'une souris et d'un hamster.
3. Rongeur modifié génétiquement selon la revendication 1 ou 2, dans lequel le gène codant pour l'IL-7 humaine ou humanisée ne comprend pas plus de cinq exons humains.
4. Rongeur modifié génétiquement selon la revendication 1, dans lequel le rongeur est une souris et le locus modifié

comprend un remplacement des exons de souris 2, 3, 4 et 5 par un segment génomique humain comprenant les exons 2, 3, 4, 5, et 6 d'IL-7 humaine.

- 5 5. Rongeur modifié génétiquement selon la revendication 1, dans lequel le gène codant pour l'IL-7 humaine ou humanisée comprend un ADNc codant pour une protéine IL-7 humaine ou humanisée.
- 10 6. Rongeur modifié génétiquement selon l'une quelconque des revendications précédentes, dans lequel l'IL-7 humaine ou humanisée est exprimée dans un profil d'expression qui est le même profil d'expression que celui observé pour un rongeur de type sauvage de la même espèce.
- 15 7. Rongeur modifié génétiquement selon la revendication 6, dans lequel le niveau de l'IL-7 humaine ou humanisée exprimée dans le rongeur est approximativement le même que le niveau d'IL-7 de rongeur dans un rongeur de type sauvage correspondant.
- 20 8. Procédé pour la création d'un rongeur avec un gène codant pour l'IL-7 humaine ou humanisée, comprenant la modification de la lignée germinale du rongeur par remplacement des exons 2 à 5 de l'IL-7 de rongeur par les exons 2 à 6 de l'IL-7 humaine pour former un gène codant pour l'IL-7 humaine ou humanisée encadré en amont et en aval par des séquences régulatrices d'IL-7 endogène de rongeur, où la modification se situe à un locus d'IL-7 endogène de rongeur.
- 25 9. Procédé selon la revendication 8, dans lequel le rongeur est choisi dans le groupe constitué d'une souris, d'un rat et d'un hamster.
- 30 10. Locus d'IL-7 humanisée comprenant un exon 1 d'IL-7 de rongeur, un exon 2 d'IL-7 humaine, un exon 3 d'IL-7 humaine, un exon 4 d'IL-7 humaine, un exon 5 d'IL-7 humaine et un exon 6 d'IL-7 humaine, où le locus d'IL-7 humanisée comprend en outre, facultativement, des régions non-traduites en 5' et 3' d'IL-7 de rongeur encadrant l'exon 1 d'IL-7 de rongeur et l'exon 6 d'IL-7 humaine et où le locus d'IL-7 humanisée comprend aussi, en outre, facultativement, une région non traduite en 3' humaine, ou une partie de celle-ci, qui est contiguë à une région non traduite en 3' de rongeur.
- 35 11. Cellule comprenant un locus d'IL-7 humanisée selon la revendication 10.
12. Cellule selon la revendication 11, qui est une cellule souche embryonnaire.
- 40 13. Tissu isolé d'un rongeur selon l'une quelconque des revendications 1 à 7, comprenant un remplacement à un locus d'IL-7 endogène de rongeur tel que défini dans l'une quelconque des revendications 1 à 7.
14. Tissu selon la revendication 13, qui est choisi dans le groupe constitué de tissu thymique, splénique, épidermique et intestinal.

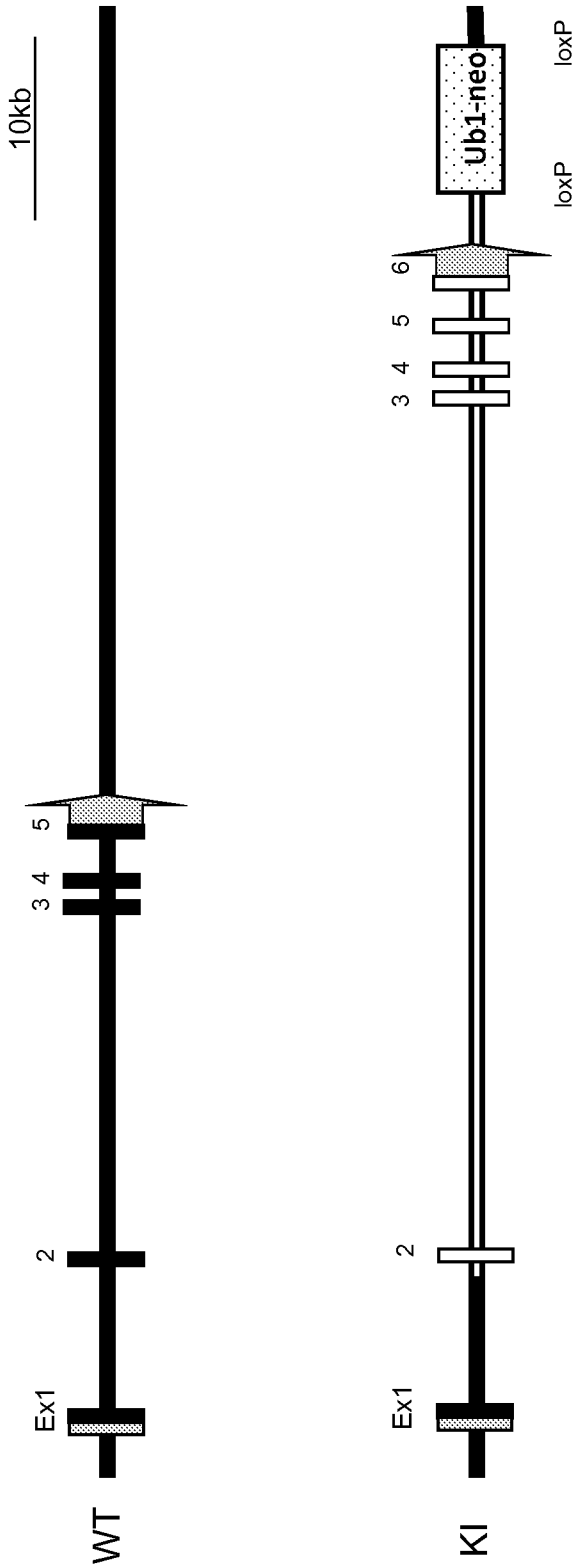


Figure 1

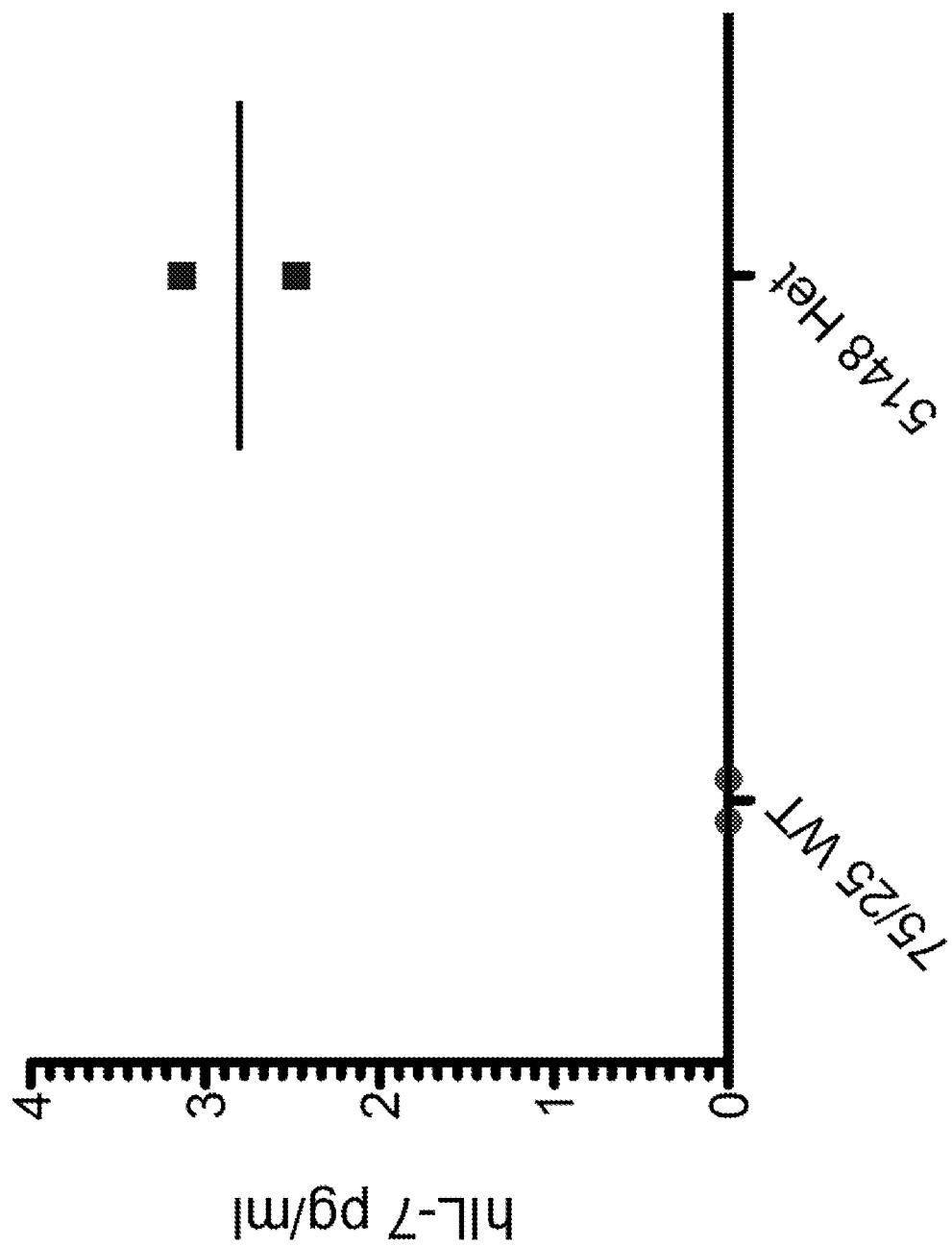


Figure 2

REFERENCES CITED IN THE DESCRIPTION

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HUMANIZÁLT IL-7 RÁGCSÁLÓK SZABADALMI IGÉNYPONTOK

1. Genetikailag módosított rágcsló, amelynek a csírvonalában a rágcsló IL-7 2-5-ös exonjait a humán IL-7 2-6-os exonjai helyettesítik, ezzel egy humán vagy humanizált IL-7-et kódoló gént hozva létre, ahol a helyettesítés egy endogén rágcsló IL-7 lokuszban történik, ahol a humán vagy humanizált IL-7-et kódoló gén endogén rágcsló IL-7 szabályozó elemek szabályozása alatt áll.
2. Az 1. igénypont szerinti genetikai módosított rágcsló, amelyet a következő csoportból választhatunk ki: patkány, egér és hörcsög.
3. Az 1. vagy 2. igénypont szerinti genetikai módosított rágcsló, ahol a humán vagy humanizált IL-7-et kódoló gén maximum öt humán exont tartalmaz.
4. Az 1. igénypont szerinti genetikai módosított rágcsló, ahol a rágcsló egy egér, és a módosított lokusz az egér 2-es, 3-as, 4-es és 5-ös exonok helyett egy humán genomális szegmenst tartalmaz, amely a humán IL-7 2-es, 3-as, 4-es, 5-ös és 6-os exonjait tartalmazza.
5. Az 1. igénypont szerinti genetikai módosított rágcsló, ahol a humán vagy humanizált IL-7-et kódoló gén egy humán vagy humanizált IL-7 fehérjét kódoló cDNS-t tartalmaz.
6. Az előző igénypontok bármelyike szerinti genetikailag módosított rágcsló, amelyben a humán vagy humanizált IL-7 olyan expressziós mintázat szerint expresszál, amely ugyanaz, mint amit az ugyanabba a fajba tartozó vad-típusú rágcslónál lehet megfigyelni.
7. A 6. igénypont szerinti genetikai módosított rágcsló, ahol a rágcslóban expresszált humán vagy humanizált IL-7 szintje körülbelül ugyanaz, mint a rágcsló IL-7 szintje egy megfelelő vad-típusú rágcslóban.
8. Eljárás egy humán vagy humanizált IL-7-et kódoló génnel rendelkező rágcsló készítésére, azzal jellemezve, hogy az eljárás a következő lépéseket tartalmazza: módosítjuk a rágcsló csírvonalát, a rágcsló IL-7 2-5-ös exonjait a humán IL-7 2-6-os exonjaival helyettesítve, ezzel egy humán vagy humanizált IL-7-et kódoló gént állítva elő, amelyet upstream és downstream endogén rágcsló IL-7 szabályozó-szekvenciák határolnak, ahol a módosítás egy endogén IL-7 lokuszban történik.
9. A 8. igénypont szerinti eljárás, azzal jellemezve, hogy a rágcslót a következő csoportból választhatjuk ki: egér, patkány és hörcsög.
10. Egy humanizált IL-7 lokusz, amely tartalmaz egy rágcsló IL-7 1-es exont, egy humán IL-7 2-es exont, egy humán IL-7 3-as exont, egy humán IL-7 4-es exont, egy humán IL-7 5-ös exont, és egy humán IL-7 6-os exont, ahol a humanizált IL-7 lokusz adott esetben tartalmaz még 5' és 3' pozícióban rágcsló IL-7 nem-transzlatódó régiókat, amelyek a rágcsló IL-7 1-es exont és a humán IL-7 6-os exont határolják, és ahol a humanizált IL-7 lokusz adott esetben tartalmaz egy 3' humán nem-transzlatódó régiót is, vagy annak egy részét, amely egybefügg egy rágcsló 3' nem-transzlatódó régióval.
11. Sejt, amely egy, a 10. igénypont szerinti humanizált IL-7 lokuszt tartalmaz.
12. A 11. igénypont szerinti sejt, amely egy embrionális őssejt.
13. Az 1-7. igénypontok bármelyike szerinti rágcslóból izolált szövet, amely egy endogén rágcsló IL-7 lokusz 1-7. igénypontok bármelyike szerinti helyettesítését tartalmazza.
14. A 13. igénypont szerinti szövet, amelyet a következő csoportból választhatunk ki: cse-csemőmirigy-, lép-, epidermális- és béliszövet.