

HUMANIZED DIPEPTIDYL PEPTIDASE IV (DPP4) ANIMALS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/005,476, filed May 30, 2014, U.S. Provisional Patent Application No. 62/051,626, filed September 17, 2014, and U.S. Provisional Patent Application No. 62/072,692, filed October 30, 2014, the disclosures of each of which are incorporated by reference herein in their entireties.

FIELD OF INVENTION

[0002] Non-human animals comprising nucleic acid sequences encoding a dipeptidyl peptidase IV (DPP4) protein that comprise a human sequence. Transgenic non-human animals comprising a *DPP4* gene that is human in whole or in part. Non-human animals that express human or humanized DPP4 proteins. Methods for making and using non-human animals comprising human or humanized *DPP4* nucleic acid sequences.

BACKGROUND

[0003] Dipeptidyl peptidase IV (DPP4) is a therapeutic target for the treatment of a variety of human diseases, disorders and conditions, including, for example, hyperglycemia (see, e.g., Gerich (2013) Pathogenesis and Management of Postprandial Hyperglycemia: Role of Incretin-Based Therapies, Intl. J. Gen. Med. 6:877-895) and Middle East respiratory syndrome coronavirus (MERS-CoV) infection (see, e.g., Raj et al. (2013) Dipeptidyl Peptidase 4 is a Functional Receptor for the Emerging Human Coronavirus-EMC, Nature 495(7440):251-254).

[0004] The evaluation of the pharmacokinetics (PK) and pharmacodynamics (PD) of therapeutic molecules that specifically target human DPP4 protein are routinely performed in non-human animals, e.g., rodents, e.g., mice or rats. However, the PD of such molecules cannot properly be determined in certain non-human animals if these therapeutic molecules also do not target the endogenous Dpp4 protein.

[0005] Moreover, the evaluation of the *in vivo* therapeutic efficacy of human DPP4-specific small molecule, peptide or protein (i.e., biologic) antagonists in non-

human animal models of diseases is problematic in certain non-human animals in which the species-specific antagonist does not interact with the endogenous Dpp4 protein. Furthermore, the evaluation of the *in vivo* therapeutic efficacy of small molecule, peptide or protein (i.e., biologic) antagonists that target molecules that specifically interact with human DPP4 protein is also problematic in certain non-human animals in which the therapeutic target molecule itself does not interact with the endogenous Dpp4 protein.

[0006] Accordingly, there is a need for non-human animals, e.g., rodents, e.g., mice or rats that comprise a human or humanized *DPP4* gene. For example, there is a need for non-human animals, e.g., rodents, e.g., mice or rats, in which the *Dpp4* gene of the non-human animal is humanized in whole or in part or replaced (e.g., at the endogenous non-human loci) with a human *DPP4* gene comprising sequences encoding human or humanized DPP4 protein.

[0007] There is also a need for non-human animals comprising a *DPP4* gene (e.g., human or humanized) in which the *DPP4* gene is under control of non-human regulatory elements (e.g., endogenous regulatory elements), for example, in the 5' flanking region, e.g., promoter and enhancer(s), or in the 3' untranslated region, of the *DPP4* gene.

[0008] There is also a need for non-human animals comprising a *DPP4* gene (e.g., human or humanized) in which the *DPP4* gene is under control of human regulatory elements, for example, in the 5' flanking region, e.g., promoter or enhancer(s), or in the 3' untranslated region, of the human *DPP4* gene.

[0009] There is also a need for humanized non-human animals that express human or humanized DPP4 protein on the surface of immune cells, e.g., T cells, and/or on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, at a level similar to that of Dpp4 protein on the surface of immune cells, e.g., T cells, and/or on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, of an age-matched non-human animal that expresses functional Dpp4 protein, but does not comprise the human or humanized *DPP4* gene.

[0010] In addition, there is a need for humanized non-human animals that express human or humanized DPP4 protein on the surface of immune cells, e.g., T cells,

and/or on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, at a level higher than or lower than that of Dpp4 protein on the surface of immune cells, e.g., T cells, and/or on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, of an age-matched non-human animal that expresses functional Dpp4 protein, but does not comprise the human or humanized *DPP4* gene.

[0011] Throughout this specification, various patents, patent applications and other types of publications (*e.g.*, journal articles, electronic database entries, *etc.*) are referenced. The disclosure of all patents, patent applications, and other publications cited herein are hereby incorporated by reference in their entirety for all purposes.

SUMMARY

[0012] Non-human animals comprising nucleic acid sequences encoding a DPP4 protein that comprises a human sequence are provided.

[0013] Transgenic non-human animals comprising a *DPP4* gene that is human in whole or in part are provided.

[0014] Non-human animals that express human or humanized DPP4 protein are provided.

[0015] Non-human animals having a replacement (in whole or in part) of the endogenous non-human animal *Dpp4* gene are provided.

[0016] Non-human animals comprising a *DPP4* humanization (in whole or in part) at an endogenous non-human *Dpp4* locus are provided.

[0017] Non-human animals are provided that have a human or humanized *DPP4* gene, wherein the non-human animals do not express endogenous Dpp4 protein, and wherein the non-human animals express human or humanized DPP4 protein on the surface of immune cells, e.g., T cells, and/or on the surface of cells in one or more tissues, including placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, at a level similar to that of Dpp4 protein present on the surface of immune cells, e.g., T cells, and/or on the surface of cells in one or more tissues, including placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, of an age-matched non-human animal that expresses functional endogenous Dpp4 protein, but does not comprise the replacement.

[0018] In one aspect, non-human animals comprising a human or humanized *DPP4* nucleic acid sequence are provided.

[0019] In one aspect, genetically modified non-human animals are provided that comprise a replacement at an endogenous *Dpp4* locus of a gene encoding an endogenous *Dpp4* gene encoding a human or humanized DPP4 protein. Rodents, e.g., mice or rats, are provided that comprise a replacement of an endogenous *Dpp4* gene, at an endogenous *Dpp4* locus, with a human *Dpp4* gene. In one embodiment, the rodent is heterozygous for a replacement at an endogenous *Dpp4* locus of an endogenous *Dpp4* gene encoding a human or humanized DPP4 protein. In one embodiment, the rodent is homozygous for a replacement at an endogenous *Dpp4* locus of an endogenous *Dpp4* gene encoding a human or humanized DPP4 protein. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0020] In one aspect, genetically modified rodents, e.g., mice or rats, are provided comprising a humanization of an endogenous rodent *Dpp4* gene, wherein the humanization comprises a replacement at the endogenous rodent *Dpp4* locus of a rodent gene encoding an exon of an *Dpp4* gene with a nucleic acid sequence encoding at least one exon of a human *DPP4* gene to form a modified *DPP4* gene, wherein expression of the modified *DPP4* gene is under control of rodent regulatory elements at the endogenous rodent *Dpp4* locus.

[0021] In one embodiment, the rodent is heterozygous for the nucleic acid sequence encoding at least one exon of a human *DPP4* gene to form a modified *DPP4* gene. In one embodiment, the rodent is homozygous for the nucleic acid sequence encoding at least one exon of a human *DPP4* gene to form a modified *DPP4* gene.

[0022] In one embodiment, the rodent is a mouse or a rat. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0023] In one embodiment, the human *DPP4* gene encoding a human or humanized DPP4 protein comprises exon 2 through exon 26 of the human *DPP4* gene.

[0024] In one embodiment, the humanized DPP4 protein comprises the extracellular domain of the human DPP4 protein.

[0025] In one embodiment, the humanized DPP4 protein comprises the transmembrane domain and cytoplasmic domain of the mouse *Dpp4* protein.

[0026] In one embodiment, the rodent is a mouse that is incapable of expressing a mouse Dpp4 protein.

[0027] In one embodiment, the rodent is a mouse wherein a contiguous genomic fragment of mouse *Dpp4* sequence encoding exon 2 through exon 26 of mouse *Dpp4* is replaced with a contiguous genomic fragment of human *DPP4* sequence encoding exon 2 through exon 26 of human *DPP4*.

[0028] In one aspect, genetically modified rodents, e.g., a mouse or rat, are provided that express a human or humanized DPP4 protein, wherein the rodent that expresses a human or humanized DPP4 protein comprises a normal immune system, i.e., the number of immune cells, e.g., T cells, in the blood, plasma or serum of the rodent expressing human or humanized DPP4 protein are similar to the number of immune cells, e.g., T cells, in the blood, plasma or serum of a rodent that expresses functional endogenous Dpp4 protein. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0029] In one embodiment, the blood of the rodent that expresses a human or humanized DPP4 protein has approximately the same number of immune cells, e.g., T cells, as a rodent that expresses a functional, endogenous Dpp4 protein, e.g., a wild-type mouse or rat. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0030] In one embodiment, the mouse expressing human or humanized DPP4 on the surface of T cells has an amount of T cells present in the blood of at least about 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130%, 140%, 150%, 160%, 170%, 180%, 190% or 200% of the amount of T cells present in the blood of an age-matched mouse that expresses functional endogenous Dpp4 protein, but does not comprise a replacement of an endogenous *Dpp4* gene, at an endogenous mouse *Dpp4* locus, with a human *DPP4* gene.

[0031] In one embodiment, the mouse expressing human or humanized DPP4 protein on the surface of T cells has an amount of T cells in the blood of between about 20% and about 200%, between about 40% and about 160%, or between about 80% and about 120% of the amount of T cells present in the blood of an age-matched mouse that expresses functional endogenous Dpp4 protein, but does not comprise a replacement of

an endogenous *Dpp4* gene, at an endogenous mouse *Dpp4* locus, with a human *DPP4* gene.

[0032] In one aspect, genetically modified rodents, e.g., a mouse or rat, are provided that express a human or humanized DPP4 protein, wherein the rodent expresses a human or humanized DPP4 protein on the surface of immune cells, e.g., T cells, and/or on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, of an age-matched rodent that expresses functional endogenous *Dpp4* protein. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0033] In one embodiment, the immune cells, e.g., T cells, of the rodent that expresses a human or humanized DPP4 protein have approximately the same level of DPP4 protein on its surface as the immune cells, e.g., T cells, of a rodent that expresses a functional, endogenous *Dpp4* protein, e.g., a wild-type mouse or rat. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0034] In one embodiment, the mouse expresses human or humanized DPP4 protein on the surface of immune cells, e.g., T cells, at a level of at least about 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130%, 140%, 150%, 160%, 170%, 180%, 190% or 200% of the level of *Dpp4* protein on the surface of immune cells, e.g., T cells, of an age-matched mouse that expresses functional endogenous *Dpp4* protein, but does not comprise a replacement of an endogenous *Dpp4* gene, at an endogenous mouse *Dpp4* locus, with a human *DPP4* gene.

[0035] In one embodiment, the mouse expresses human or humanized DPP4 protein on the surface of immune cells, e.g., T cells, at a level of between about 20% and about 200%, between about 40% and about 160%, or between about 80% and about 120% of the level of mouse *Dpp4* protein present on the surface of immune cells, e.g., T cells, of an age-matched mouse that expresses functional endogenous *Dpp4* protein, but does not comprise a replacement of an endogenous *Dpp4* gene, at an endogenous mouse *Dpp4* locus, with a human *DPP4* gene.

[0036] In one embodiment, the cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, of the rodent that expresses a human or humanized DPP4 protein have approximately the same level of DPP4 protein on its surface as the cells in one or more tissues, e.g., placenta, kidney, lung, liver,

skeletal muscle, heart, brain and/or pancreas, of a rodent that expresses a functional, endogenous *Dpp4* protein, e.g., a wild-type mouse or rat. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0037] In one embodiment, the mouse expresses human or humanized *DPP4* protein on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, at a level of at least about 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130%, 140%, 150%, 160%, 170%, 180%, 190% or 200% of the level of *Dpp4* protein on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, of an age-matched mouse that expresses functional endogenous *Dpp4* protein, but does not comprise a replacement of an endogenous *Dpp4* gene, at an endogenous mouse *Dpp4* locus, with a human *DPP4* gene.

[0038] In one embodiment, the mouse expresses human or humanized *DPP4* protein on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, at a level of between about 20% and about 200%, between about 40% and about 160%, or between about 80% and about 120% of the level of mouse *Dpp4* protein present on the surface of cells in one or more tissues, e.g., placenta, kidney, lung, liver, skeletal muscle, heart, brain and/or pancreas, of an age-matched mouse that expresses functional endogenous *Dpp4* protein, but does not comprise a replacement of an endogenous *Dpp4* gene, at an endogenous mouse *Dpp4* locus, with a human *DPP4* gene.

[0039] In one aspect, a genetically modified rodent is provided, comprising a humanized *DPP4* gene comprising a replacement of rodent *Dpp4* extracellular domain-encoding sequence with human *DPP4* extracellular domain-coding sequence, wherein the humanized *DPP4* gene comprises a rodent *Dpp4* transmembrane sequence and a rodent *Dpp4* cytoplasmic sequence, wherein the humanized *DPP4* gene is under control of endogenous rodent *Dpp4* regulatory elements at the endogenous *Dpp4* locus.

[0040] In one embodiment, the rodent is heterozygous for the humanized *DPP4* gene. In one embodiment, the rodent is homozygous for the humanized *DPP4* gene.

[0041] In one embodiment, the rodent is a mouse or a rat. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0042] In one embodiment, the mouse is incapable of expressing a mouse *Dpp4* protein.

[0043] In one embodiment, the rodent regulatory elements or sequences at the endogenous rodent *Dpp4* locus are from a mouse or a rat.

[0044] In one embodiment, the rodent regulatory elements or sequences are endogenous rodent regulatory elements or sequences at the rodent *Dpp4* locus are from a mouse or a rat.

[0045] In one aspect, a non-human animal, e.g., a rodent, e.g., a mouse or rat, is provided that expresses human or humanized DPP4 protein, wherein the non-human animal expresses human or humanized DPP4 protein from an endogenous non-human *Dpp4* locus. In an embodiment, the non-human animal is a rodent. In an embodiment, the rodent is a mouse. In an embodiment, the rodent is a rat. In one embodiment, the rodent is heterozygous for the endogenous non-human *Dpp4* locus expressing a human or humanized DPP4 protein. In one embodiment, the rodent is homozygous for the endogenous non-human *Dpp4* locus expressing a human or humanized DPP4 protein.

[0046] In one aspect, a genetically modified mouse is provided that expresses human or humanized DPP4 protein from an endogenous mouse *Dpp4* locus, wherein the endogenous mouse *Dpp4* gene has been replaced, in whole or in part, with a human *DPP4* gene.

[0047] In one embodiment, about 78.8 kb at the endogenous mouse *Dpp4* locus, including exon 2 through the stop codon in exon 26, is deleted and replaced with about 81.8 kb of human *DPP4* gene sequence comprising exon 2 through exon 26 and a portion of the 3' untranslated sequence of the human *DPP4* gene. In a specific embodiment, the human *DPP4* gene comprises exon 2 through exon 26 and a portion of the 3' untranslated sequence of the human *DPP4* gene of human BAC RP11-68L22. In a specific embodiment, the *DPP4* gene comprises mouse *Dpp4* gene 5' regulatory elements, mouse *Dpp4* exon 1, including the first two amino acids, Met and Lys, of the mouse *Dpp4* protein, and mouse *Dpp4* 3' regulatory elements (e.g., 3' untranslated region), and human *DPP4* gene exon 2 through exon 26, i.e., the human DPP4 protein coding sequences, except for the first two amino acids, which are derived from mouse *Dpp4* exon 1.

[0048] In one aspect, a genetically modified mouse is provided that comprises a nucleotide sequence encoding a human or humanized DPP4 protein, wherein the nucleotide sequence encoding the human or humanized DPP4 protein replaces, in whole or in part, an endogenous nucleotide sequence encoding an endogenous mouse *Dpp4* protein.

[0049] In one embodiment, the mouse is heterozygous for the nucleotide sequence encoding a human or humanized DPP4 protein. In one embodiment, the mouse is homozygous for the nucleotide sequence encoding a human or humanized DPP4 protein.

[0050] In one aspect, a method is provided for making a humanized DPP4 rodent, comprising replacing a rodent *Dpp4* gene sequence encoding rodent *Dpp4* protein with a human *DPP4* gene sequence comprising one or more exons of the human *DPP4* gene sequence encoding human or humanized DPP4 protein, wherein the replacement is at an endogenous rodent *Dpp4* locus and the human *DPP4* gene sequence comprising one or more exons of the human *DPP4* gene sequence encoding human or humanized DPP4 protein is operably linked to rodent regulatory elements or sequences at the endogenous rodent *Dpp4* locus.

[0051] In one embodiment, the rodent is heterozygous for the nucleotide sequence encoding a human or humanized DPP4 protein. In one embodiment, the rodent is homozygous for the nucleotide sequence encoding a human or humanized DPP4 protein.

[0052] In one embodiment, the rodent is a mouse or a rat. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0053] In one embodiment, the rodent regulatory elements or sequences are derived from a mouse. In one embodiment, the rodent regulatory elements or sequences are derived from a rat.

[0054] In one embodiment, the rodent regulatory elements or sequences are endogenous rodent regulatory elements or sequences at the rodent *Dpp4* locus. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0055] In one embodiment, the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises at least one exon of the human *DPP4* gene sequence. In other embodiments, the human *DPP4* gene sequence replacing the rodent *Dpp4* gene

sequence comprises at least 2, at least 3, at least 4, at least 5, at least 6, at least 7, at least 8, at least 9, at least 10, at least 11, at least 12, at least 13, at least 14, at least 15, at least 16, at least 17, at least 18, at least 19, at least 20, at least 21, at least 22, at least 23, at least 24, or at least 25 exons of the human *DPP4* gene sequence. In one embodiment, the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises all 26 exons of the human *DPP4* gene sequence. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0056] In one embodiment, the human or humanized *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence encodes a protein that is about 85%, 90%, 95%, 96%, 97%, 98%, or about 99% identical to a human DPP4.

[0057] In one embodiment, the human or humanized *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises at least one exon of the human *DPP4* gene sequence encoding the extracellular domain of the human DPP4 protein. In other embodiments, the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises at least 2, at least 3, at least 4, at least 5, at least 6, at least 7, at least 8, at least 9, at least 10, at least 11, at least 12, at least 13, at least 14, at least 15, at least 16, at least 17, at least 18, at least 19, at least 20, at least 21, at least 22, or at least 23 exons of the human *DPP4* gene sequence encoding the extracellular domain of the human DPP4 protein. In one embodiment, the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises all 24 exons of the human *DPP4* gene sequence encoding the extracellular domain of the human DPP4 protein. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0058] In one embodiment, the human or humanized *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence encodes an extracellular domain of the DPP4 protein that is about 85%, 90%, 95%, 96%, 97%, 98%, or about 99% identical to the extracellular domain of a human DPP4 protein.

[0059] In one embodiment, the replacement is at an endogenous rodent *Dpp4* locus and the human *DPP4* gene sequence comprising one or more exons of the human *DPP4* gene sequence encoding human or humanized DPP4 protein is operably linked to endogenous rodent regulatory elements or sequences at the endogenous rodent *Dpp4* locus.

[0060] In one aspect, a method is provided for making a humanized DPP4 mouse, comprising replacing a mouse *Dpp4* gene sequence encoding mouse Dpp4 protein with a human *DPP4* gene sequence encoding human or humanized DPP4 protein.

[0061] In one embodiment, the replacement is at an endogenous mouse *Dpp4* locus, and the human *DPP4* gene encoding human or humanized DPP4 protein is operably linked to mouse regulatory elements or sequences at the endogenous mouse *Dpp4* locus.

[0062] In one embodiment, the replacement is at an endogenous mouse *Dpp4* locus, and the human *DPP4* gene encoding human or humanized DPP4 protein is operably linked to endogenous mouse regulatory elements or sequences at the endogenous mouse *Dpp4* locus.

[0063] In various aspects, the genetically modified non-human animals, e.g., rodents, e.g., mice or rats, described herein comprise the genetic modifications in their germ-line.

[0064] In one aspect, a non-human animal, e.g., rodent, e.g., a mouse or rat, embryo comprising a genetic modification as described herein is provided.

[0065] In one aspect, a non-human animal, e.g., rodent, e.g. a mouse or rat, host embryo is provided that comprises a donor cell that comprises a genetic modification as described herein.

[0066] In one aspect, a pluripotent or totipotent non-human animal, e.g., rodent, e.g., mouse or rat, cell comprising a genetic modification as described herein is provided. In one embodiment, the cell is a rodent cell. In one embodiment, the cell is a mouse cell. In one embodiment, the cell is a rodent embryonic stem (ES) cell. In one embodiment, the cell is a mouse ES cell.

[0067] In one aspect, a non-human animal, e.g., rodent, e.g., mouse or rat, egg is provided, wherein the non-human animal egg comprises an ectopic non-human animal chromosome, wherein the ectopic non-human animal chromosome comprises a genetic modification as described herein. In one embodiment, the non-human animal is a rodent. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0068] In one aspect, the mouse embryo, egg, or cell that is genetically modified to comprise a human *DPP4* gene is of a mouse that is 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/Ola. 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 yet another embodiment, the mouse is a mix of a BALB strain and another aforementioned strain. In one embodiment, the mouse is Swiss or Swiss Webster mouse.

[0069] In various aspects, the non-human animals comprising a human or humanized *DPP4* nucleic acid sequence are selected from mammals and birds. In one embodiment, the non-human animals are mammals. In one embodiment, the mammals are rodents. In one embodiment, the rodents are mice or rats.

[0070] In one aspect, a rodent is provided that comprises a nucleic acid sequence comprising a human *DPP4* gene or fragment thereof, where the human *DPP4* gene or fragment thereof comprises at least one exon of the human *DPP4* gene, and where the human *DPP4* gene or fragment thereof encodes a human or humanized DPP4 protein.

[0071] In one embodiment, the human *DPP4* gene or fragment thereof comprises at least 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 18, 20, 21, 22, 23, 24, or 25 exons of the human *DPP4* gene.

[0072] In one embodiment, the human *DPP4* gene or fragment thereof comprises all 26 exons of the human *DPP4* gene.

[0073] In one embodiment, the nucleic acid sequence further comprises a 5' flanking region of the human *DPP4* gene. In one embodiment, the human *DPP4* gene or fragment thereof is operably linked to the 5' flanking region of the human *DPP4* gene. In one embodiment, the 5' flanking region of the human *DPP4* gene comprises at least 1 kb

in length (e.g., at least 1, 2, 3, 4, 5, 10, 20, 30, 40, 50 kb, or greater, in length). In one embodiment, the 5' flanking region of the human *DPP4* gene comprises at least 10 kb in length. In one embodiment, the 5' flanking region of the human *DPP4* gene comprises at least 40 kb in length.

[0074] In one embodiment, expression of the human *DPP4* gene or fragment thereof is under control of the 5' flanking region of the human *DPP4* gene.

[0075] In one embodiment, the human or humanized DPP4 protein comprises the amino acid sequence of SEQ ID NO: 24 or a fragment thereof.

[0076] In one embodiment, the rodent expresses the human or humanized DPP4 protein on the surface of T cells in a level that is at least about 20% (e.g., at least about 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 98%, 99%, or greater) of the level of rodent Dpp4 protein present on the surface of T cells of an age-matched rodent that expresses functional endogenous rodent Dpp4 protein but that does not comprise the human *DPP4* gene or fragment thereof.

[0077] In one embodiment, the rodent expresses the human or humanized DPP4 protein on the surface of cells in one or more tissues selected from the group consisting of placenta, kidney, lung, liver, skeletal muscle, heart, brain, and pancreas, in a level that is at least about 20% (e.g., at least about 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 98%, 99%, or greater) of the level of rodent Dpp4 protein present on the surface of one or more tissues of an age-matched rodent that expresses functional endogenous rodent Dpp4 protein but that does not comprise the human *DPP4* gene or fragment thereof.

[0078] In one embodiment, the rodent expresses functional endogenous rodent Dpp4 protein.

[0079] In one embodiment, the rodent is a mouse or a rat.

[0080] In one aspect, provided herein is a method for making a humanized transgenic rodent, comprising integrating a nucleic acid sequence comprising one or more exons of a human *DPP4* gene sequence into a chromosome of a rodent, where the one or more exons of the human *DPP4* gene sequence encodes a human or humanized DPP4 protein.

[0081] In one embodiment, the human *DPP4* gene or fragment thereof comprises at least 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 18, 20, 21, 22, 23, 24, or 25 exons of the human *DPP4* gene.

[0082] In one embodiment, the human *DPP4* gene or fragment thereof comprises all 26 exons of the human *DPP4* gene.

[0083] In one embodiment, the nucleic acid sequence further comprises a 5' flanking region of the human *DPP4* gene.

[0084] In one embodiment, the human *DPP4* gene sequence is operably linked to the 5' flanking region of the human *DPP4* gene.

[0085] In one embodiment, the human or humanized DPP4 protein comprises the amino acid sequence of SEQ ID NO: 24 or a fragment thereof.

[0086] In one embodiment, the rodent is a mouse or a rat. In further aspects, methods for determining the *in vivo* therapeutic efficacy of a human-specific DPP4 antagonist in any of the humanized *DPP4* rodents described herein are provided, the method comprising administering to the rodent a DPP4 antagonist, wherein the rodent is infected with Middle East respiratory syndrome coronavirus (MERS-CoV); and determining if whether the DPP4 antagonist treats or prevents one or more symptoms of MERS-CoV infection compared to control rodents infected with MERS-CoV who have not been administered the DPP4 antagonist.

[0087] In one embodiment, the DPP4 antagonist is selected from the group consisting of small molecules, peptides and antibodies.

[0088] In one embodiment, the DPP4 antagonist is an antibody to a MERS-CoV protein.

[0089] In one embodiment, the MERS-CoV protein is MERS-CoV spike protein.

[0090] In one embodiment, the rodent is infected with one or more strains of MERS-CoV selected from the group consisting of Al-Hasa_1, Al-Hasa_2, Al-Hasa_3, Al-Hasa_4, Al-Hasa_12, Al-Hasa_15, Al-Hasa_16, Al-Hasa_17, Al-Hasa_18, Al-Hasa_19, Al-Hasa_21, Al-Hasa_25, Buraidah_1, EMC/2012, FRA/UAE, Hafr-Al-Batin_1, Hafr-Al-Batin_2, Hafr-Al-Batin_6, Jeddah_1, Jordan-N3/2012, Munich, Riyadh_3, Riyadh_4, Riyadh_5, Riyadh_14, Taif_1, Wadi-Ad-Dawasir_1, Riyadh_9, KFU-HKU 1, KFU-HKU 13, Qatar3, Qatar4, England 1, England-Qatar/2012, Bisha_1, Riyadh_1, and Riyadh_2.

[0091] In one embodiment, the antagonist is administered before MERS-CoV infection. In one embodiment, the antagonist is administered after MERS-CoV infection.

[0092] In one embodiment, the antagonist is administered simultaneously with MERS-CoV infection.

[0093] In one embodiment, the symptom of MERS-CoV infection is viral titer or RNA level.

[0094] In one embodiment, the viral titer or RNA level is assessed by one or more methods selected from the group consisting of qPCR, Northern Blot, plaque assay, and *in situ* hybridization.

[0095] In one embodiment, the symptom of MERS-CoV infection is lung inflammation.

[0096] In one embodiment, the lung inflammation is assessed histochemically.

[0097] In one embodiment, the symptom of MERS-CoV infection is weight loss.

[0098] In one embodiment, the rodent is a mouse or a rat. In one embodiment, the rodent is a mouse. In one embodiment, the rodent is a rat.

[0099] Each of the aspects and embodiments described herein are capable of being used together, unless excluded either explicitly or clearly from the context of the embodiment or aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

[00100] **Figures 1A-B** provide illustrations, not to scale, of the strategy for humanization of the *Dpp4* locus. Figure 1A is a schematic showing that 78.8 kb of the mouse *Dpp4* gene (top) spanning exon 2 through the stop codon in exon 26 are deleted and replaced with 81.7 kb of the human *DPP4* gene (bottom) spanning exon 2 through exon 26 and a portion of the 3' untranslated region, as indicated. Figure 1B is a schematic showing that the humanized *DPP4* mouse comprises (i) the mouse *Dpp4* gene 5' flanking region, including the regulatory sequences, e.g., promoter and transcription start site, and exon 1, including the initiation ATG codon, (ii) the human *DPP4* gene spanning exon 2 through exon 26, including the Stop codon, and a portion of the 3' untranslated region, including the loxP site, and (iii) the mouse *Dpp4* gene 3' untranslated region starting from just 3' to the Stop codon, as indicated.

[00101] **Figure 2** shows the amino acid sequence (SEQ ID NO:17) of the humanized DPP4 protein expressed in the humanized *DPP4* mice.

[00102] **Figure 3** shows the results of real-time PCR performed on RNA obtained from lung tissue from either mock (PBS)-infected, or MERS-CoV (Jordan strain)-infected, F0 humanized *DPP4* mice 4 days after infection.

[00103] **Figure 4** shows the H&E staining of airway (10X and 40X magnification) and alveoli (40X magnification) from the lungs of either mock (PBS)-infected, or MERS-CoV (Jordan strain)-infected, F0 humanized *DPP4* mice 4 days after infection.

[00104] **Figure 5** is a sequence alignment of the mouse *Dpp4* (mDpp4) amino acid sequence (SEQ ID NO: 25) with the human DPP4 (hDPP4) protein encoded by the transgenic MAID 7326/7327 mice (SEQ ID NO: 26). Non-homologous residues that differ between the sequences are underlined, homologous residues that differ between the sequences are bolded and italicized, and gaps are indicated by hyphens. Residues that are identical between the two sequences are shown in unformatted text.

[00105] **Figure 6** is a table displaying gene, sequence, and chromosomal information for human *DPP4*.

[00106] **Figure 7** is a schematic showing the coverage of the human *DPP4* gene and flanking genomic sequences for each of the BACs, BAC RP11-345J9 and BAC RP11-68L22. The locations within the human *DPP4* gene and promoter regions at which the human TaqMan™ primer-probe sets anneal are also shown (7333hTU for the upstream set and 7333hTD for the downstream set).

[00107] **Figure 8** is a table displaying the primer-probe sets used for the human TaqMan™ gain of allele assays, where 7333 hTU refers to the upstream set and 7333 hTD refers to the downstream set.

[00108] **Figure 9** is the amino acid sequence of the humanized DPP4 protein encoded by the transgenic MAID 7333 and 7334 mice (SEQ ID NO: 24).

[00109] **Figure 10A** is a bar graph showing quantitative PCR measurements of MERS-CoV genome (UpE RNA) in infected mice 2 and 4 days post-infection (dpi).

Figure 10B is a bar graph showing quantitative PCR measurements of MERS-CoV mRNA transcript (leader RNA) in infected mice on 2 dpi and 4 dpi. **Figure 10C** is a bar graph quantifying MERS-CoV viral titer of infected mouse lung at 2 dpi and 4 dpi. MERS-CoV levels in homogenized mouse lung were quantified by 50% Tissue Culture

Infective Dose (TCID₅₀) assay and expressed as plaque forming units (pfu) per mL.

Figure 10D is a panel of histological images, stained with Hematoxylin and Eosin, of lungs from MERS-CoV infected mice. Airway (10X), vasculature (10X) and interstitium (40X) are shown for PBS, 2 dpi, and 4 dpi mice.

[00110] **Figure 11A** is a bar graph showing quantitative PCR measurements of MERS-CoV genome (UpE RNA) from lungs of mice pre-treated with anti-MERS-CoV spike protein antibodies (Ab 2 or Ab 4) before viral infection. **Figure 11B** is a bar graph showing quantitative PCR measurements of MERS-CoV mRNA transcript (leader RNA) from lungs of mice pre-treated with anti-MERS-CoV spike protein antibodies before viral infection. RNA was quantified using primers directed against the MERS-CoV genome and compared to hlgG1 isotype control treated mice. All samples were compared to hlgG1 control set at 100%. **Figure 11C** is a bar graph showing the viral titer in lungs of mice pre-treated with anti-MERS-CoV spike protein antibodies before viral infection. Viral titer was quantitated by plaque assay and reported as pfu/mL.

[00111] **Figure 12A** is a panel of histological images of lungs of MERS-CoV infected B6/*hDPP4* mice with anti-MERS-CoV spike protein antibody (Ab 2 or Ab 4) pre-treatment. Hematoxylin and Eosin stained sections of mouse lung showing airway, vasculature and interstitium of a representative mouse from each group. **Figure 12B** is a bar graph showing the histological scoring of the mouse lungs shown in **Figure 12A**. The scores were the average scores of all mice in each experimental group and time point.

[00112] **Figure 13A** is a bar graph showing quantitative PCR measurements of MERS-CoV genome (UpE RNA) from infected lungs. Effects of anti-MERS-CoV spike protein antibodies (Ab 2 or Ab 4) injected one day before or one day after viral infection were compared. **Figure 13B** is a bar graph showing quantitative PCR measurements of MERS-CoV mRNA transcript (leader RNA) from infected lungs. Effects of anti-MERS-CoV spike protein antibodies (Ab 2 or Ab 4) injected one day before or one day after viral infection were compared. For Figures 13A-B, RNA was quantified using primers directed against the MERS-CoV genome and compared to hlgG1 isotype control treated mice. All samples were compared to hlgG1 control set at 100%. **Figure 13C** is a bar graph showing the viral titer in lungs of mice treated with anti-MERS-CoV spike protein antibodies (Ab 2 or Ab 4) after viral infection. Viral titer was quantitated by plaque

assay and reported as PFU/mL lung. Effects of antibodies injected one day before or one day after viral infection were compared.

[00113] **Figure 14A** is a panel of histological images of lungs from MERS-CoV infected B6/*hDPP4* mice with anti-MERS-CoV spike protein Ab 2 antibody treatment at 1 day post-infection. Hematoxylin and Eosin stained sections of mouse lung show airway, vasculature, and interstitium of a representative mouse from each group.

Figure 14B is a bar graph showing the histological scoring of the mouse lungs of Figure 14A.

[00114] **Figure 15** depicts a dose-response study of weight as a function of time post-infection with MERS-CoV in humanized DPP4 mice. 4-5 mice are used per group.

[00115] **Figure 16** depicts a dose-response study of weight as a function of time post-infection with MERS-CoV (1×10^6 pfu/mouse; 4-5 mice per group) in heterozygotic and homozygotic humanized DPP4 mice.

[00116] **Figure 17** depicts pathology (inflammation) as seen by histological examination at day 7 in a humanized DPP4 mouse exposed to a high dose of virus (1×10^6 pfu/mouse) versus PBS-treated controls.

DETAILED DESCRIPTION

DPP4 Gene and Protein

[00117] The *DPP4* gene encodes the type II transmembrane protein, tripeptidyl peptidase IV (DPP4) (also known as CD26, adenosine deaminase complexing protein-2 (ADCP2), adenosine deaminase binding protein (ADABP), and TP103), which has serine exopeptidase activity, and which plays an important role in the activation of T cells and in intracellular signal transduction cascades in several other cell types.

[00118] *Human DPP4*. NCBI Gene ID: 1803; Primary source: HGNC:3009; RefSeq transcript: NM_001935.3; UniProt ID: P27487; Genomic assembly: GRCh38; Location: chr2:162,848,755-162,931,052 - strand. (See Figure 6).

[00119] The human *DPP4* gene is located on chromosome 2, at 2q24.3. The human *DPP4* gene has 26 exons and encodes a type II transmembrane polypeptide of 766 amino acids in length, including an N-terminal 6 amino acid cytoplasmic domain, a 22 amino acid transmembrane domain, and a C-terminal 738 amino acid extracellular

domain. The extracellular domain (i.e., ectodomain) of the human DPP4 protein is encoded by coding exons 3 through 26 of the human *DPP4* gene.

[00120] *Mouse Dpp44*. NCBI Gene ID: 13482; Primary source: MGI:94919; RefSeq transcript: NM_010074.3; UniProt ID: P28843; Genomic assembly: GRCh38; Location: chr2:62,330,073-62,412,591 – strand.

[00121] The mouse *Dpp4* gene is located on chromosome 2, at 2 35.85 cM. The mouse *Dpp4* gene has 26 exons and encodes a type II transmembrane polypeptide of 760 amino acids in length, including an N-terminal 6 amino acid cytoplasmic domain, a 22 amino acid transmembrane domain, and a C-terminal 732 amino acid extracellular domain. The extracellular domain (i.e., ectodomain) of the mouse *Dpp4* protein is encoded by coding exons 3 through 26 of the mouse *Dpp4* gene.

Species Specificity of DPP4 Protein

[00122] As discussed below in Example 2, the human, but not the mouse, DPP4 protein is a functional receptor for the Middle East respiratory syndrome coronavirus (MERS-CoV) infection.

[00123] Candidate therapeutic molecules that target the human DPP4 protein in a species-specific manner, or target molecules, such as MERS-CoV, which interact with the human DPP4 protein in a species-specific manner, are typically evaluated for pharmacokinetics (PK) and pharmacodynamics (PK) in non-human animals, e.g., rodents, e.g., mice or rats. Such therapeutic molecules are also tested for *in vivo* therapeutic efficacy in non-human animal, e.g., rodent, e.g., mouse or rat, models of human diseases, disorders and conditions in which DPP4 plays a role.

[00124] However, therapeutic molecules that are specific for the human DPP4 protein, e.g., human-specific DPP4 inhibitors, cannot be adequately evaluated for PD and/or *in vivo* therapeutic efficacy in rodents, in particular mice, because the targets of these therapeutic molecules are missing.

[00125] Moreover, therapeutic molecules that are specific for targets that specifically interact with human DPP4 protein, e.g., human DPP4-specific MERS-CoV, cannot be adequately evaluated for *in vivo* therapeutic efficacy in rodents, in particular mice, because the targets (e.g., receptor, interaction partner) of these therapeutic target molecules are missing.

[00126] Accordingly, in various embodiments, to assess the PD and/or *in vivo* therapeutic efficacy of a human-specific DPP4 protein antagonist or inhibitor in non-human animals, e.g., rodents, e.g., mice or rats, it is desirable to replace the endogenous Dpp4 protein with human or humanized DPP4 protein. In various embodiments, to assess the *in vivo* therapeutic efficacy of small molecules, peptides or biologic antagonists or inhibitors of a target molecule that specifically interacts with a human DPP4 protein in non-human animals, e.g., rodents, e.g., mice or rats, it is desirable to replace the endogenous Dpp4 protein with human or humanized DPP4 protein.

[00127] Further, in various embodiments, in order to avoid potential problems of the over- or under-expression of the human or humanized DPP4 protein, and/or the inappropriate expression of the human or humanized DPP4 protein in cells or tissues in which the endogenous Dpp4 protein is not normally expressed, it is desirable to insert the human *DPP4* gene, in whole or in part, into the genome of the non-human animals, e.g., rodents, e.g., mice or rats, at the endogenous *Dpp4* gene loci, and to express the human or humanized DPP4 protein in non-human animals, e.g., rodents, e.g., mice or rats, under the control, at least in part, of the endogenous *Dpp4* regulatory elements.

[00128] In some embodiments, targeted replacement of the endogenous, e.g., mouse or rat, Dpp4 gene by the human DPP4 gene or fragment thereof is desirable.

[00129] In other embodiments, the human DPP4 gene or fragment thereof is randomly inserted into the rodent, e.g., mouse or rat, genome instead of replacing the endogenous Dpp4 gene with a human DPP4 gene or fragment thereof. In some embodiments, in rodents, e.g., mice or rats, in which the human DPP4 gene or fragment thereof has been randomly inserted into the genome, expression of endogenous rodent Dpp4 is retained.

[00130] Provided herein are non-human animals, e.g., rodents, e.g., mice or rats, that comprise a human *DPP4* gene or fragment thereof either at (i.e., replacing) the endogenous *Dpp4* locus, or at one or more other loci. Also provided herein are non-human animals, e.g., rodents, e.g., mice or rats, that comprise a human *DPP4* gene or fragment thereof both at (i.e., replacing) the endogenous *Dpp4* locus, and at an additional locus/loci.

[00131] In some embodiments, a fragment of a human DPP4 gene contains 200 kilobases (kb) or fewer nucleotides, e.g., 180, 160, 140, 120, 100, 80, 70, 60, 50, 40, 30,

20, 10, 5, 2.5, 1 kb or fewer nucleotides, e.g., 1000, 800, 600, 400, 200, or fewer nucleotides.

Generation of Cells and Non-Human Animals with Human *DPP4*

[00132] For targeted replacement of an endogenous non-human *Dpp4* gene or fragment with a human *DPP4* gene or fragment, a targeting construct is generated. See, e.g., Valenzuela et al. Nature Biotech, 21.6(2003):652-659; US 6,586,251; and US 8,759,105. For example, a targeting construct comprises homology arms flanking a replacement human *DPP4* gene or fragment thereof.

[00133] In some embodiments, the replacement human *DPP4* gene or fragment thereof comprises the entire human *DPP4* gene. In other embodiments, the replacement human *DPP4* gene or fragment thereof comprises a portion of the human *DPP4* gene. For example, the replacement human *DPP4* gene or fragment thereof comprises one or more exons of human *DPP4* gene, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, or 26 exons of the human *DPP4* gene. For example, the replacement human *DPP4* gene or fragment thereof comprises the exons 1-26 of the human *DPP4* gene. In other embodiments, the replacement human *DPP4* gene or fragment thereof comprises exons 2-26 of the human *DPP4* gene. For example, the replacement human *DPP4* gene or fragment thereof comprises intron 1 upstream of exon 2 through exon 26 of the human *DPP4* gene. In some embodiments, the replacement human *DPP4* gene or fragment thereof further comprises a human regulatory element(s), e.g., a portion of the human 3' untranslated region (UTR) downstream of the human *DPP4* gene, for example at least 1 kb of downstream region (e.g., at least 1, 2, 3, 4, 5, 10, 20, 30, 40 Kb, or greater), and/or a human promoter or enhancer region upstream of the human *DPP4* gene, for example, at least 10 kb of upstream region (e.g., at least 10, 20, 30, 40, 50 Kb, or greater).

[00134] Homology arms are sequences that are homologous to endogenous chromosomal nucleic acid sequences flanking the desired genetic modification/replacement, e.g., flanking the endogenous *Dpp4* gene or fragment that is to be replaced. Homologous nucleic acid sequences can be two or more nucleic acid sequences that are either identical or similar enough that they are able to hybridize to each other or undergo intermolecular exchange. Due to the homology between the homology arms and the corresponding endogenous sequence, the homology arms direct

the targeting construct to a specific chromosomal location within the genome, e.g., the endogenous *Dpp4* gene locus. See, e.g., Valenzuela et al. Nature Biotech, 21.6(2003):652-659; US 6,586,251; and US 8,759,105.

[00135] Optionally, the targeting construct further comprises a selection marker, e.g., in between the two homology arms. Exemplary selection markers include antibiotic resistance markers (e.g., neomycin or kanamycin) and fluorescent proteins. In some embodiments, the selection marker is floxed, i.e., flanked by two loxP sites. The floxed selection marker can be removed by the addition of Cre recombinase, which catalyzes the excision of the floxed segment, e.g., including the selection marker.

[00136] Vector/Constructs

[00137] The transgenic non-human animals (e.g., rodents, e.g., mice or rats) of the invention can be made by using various vectors and/or constructs. In some embodiments, the targeting construct is in the form of a circular piece of double-stranded DNA, e.g., a bacterial artificial chromosome (BAC), plasmid, or P1-derived artificial chromosome (PAC).

[00138] To generate a non-human cell comprising a targeted replacement of the endogenous *Dpp4* locus, a targeting construct containing a human *DPP4* gene or fragment described herein is introduced into a non-human (e.g., rodent, e.g., mouse or rat) cell, e.g., embryonic stem (ES) cell.

[00139] To generate a non-human cell comprising a human *DPP4* gene or fragment randomly inserted into the genome, a circular DNA construct, e.g., BAC, containing a human *DPP4* gene or fragment thereof, is introduced into a non-human (e.g., rodent, e.g., mouse or rat) cell, e.g., ES cell. In some cases, the circular DNA construct, e.g., BAC, further contains a human *DPP4* regulatory element, e.g., a human promoter or enhancer region upstream and/or downstream of human *DPP4* gene. For example, the circular DNA construct contains at least 10 kb (e.g., at least 10, 20, 30, 40, 50 kb or greater) of promoter/enhancer region upstream of the ATG start codon of the human *DPP4* gene. In addition or alternatively, the circular DNA construct contains at least 1 kb (e.g., at least 1, 2, 3, 4, 5, 10, 20, 30, 40 kb or greater) of untranslated region downstream of the human *DPP4* gene. For example, the human *DPP4* gene or fragment is operably linked to the human *DPP4* regulatory element.

[00140] In some embodiments, the human *DPP4* gene or fragment thereof in the circular DNA construct (e.g., BAC) comprises the entire human *DPP4* gene. In other

embodiments, the human *DPP4* gene or fragment thereof comprises a portion of the human *DPP4* gene. For example, the human *DPP4* gene or fragment thereof comprises one or more exons of human *DPP4* gene, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, or 26 exons of the human *DPP4* gene. For example, the human *DPP4* gene or fragment thereof comprises the exons 1-26 of the human *DPP4* gene. In other embodiments, the human *DPP4* gene or fragment thereof comprises exons 2-26 of the human *DPP4* gene. For example, the human *DPP4* gene or fragment thereof comprises intron 1 upstream of exon 2 through exon 26 of the human *DPP4* gene.

[00141] For example, the introduction step into the cell is done by electroporation or lipid-mediated transfection.

[00142] Optionally, the circular DNA construct, e.g., BAC, is linearized before introduction into the cell. For example, linearization is performed with rare-cutting restriction enzymes, e.g., SgrDI, SfiI, NotI, PaeI, or Swal.

[00143] In cases in which the targeting construct comprises an antibiotic selection marker (e.g., neomycin), cells that have taken up the targeting construct are optionally selected in neomycin/G418-containing media. Cells that survive and/or proliferate in neomycin/G418-containing media are selected and positive for the targeting construct.

[00144] In some embodiments, the cell population is screened for those cells that have incorporated into their genome a human *DPP4* gene or fragment thereof, e.g., randomly inserted into the genome or targeted (e.g., by the targeting construct) to the endogenous *Dpp4* locus.

[00145] Methods for screening include quantitative PCR and fluorescence in situ hybridization. See, e.g., US 6,586,251 B2 and US 8,759,105 B2. For example, methods of screening include detecting for the presence of a human *DPP4* gene or fragment. In some embodiments, methods of screening include detecting for a loss of copy number of endogenous *Dpp4* gene or fragment and/or gain of copy number of human *DPP4* gene or fragment. Exemplary methods of screening are described in Examples 1 and 3.

[00146] In some embodiments in which the targeting construct comprises a floxed selection marker, correctly targeted cells are optionally further electroporated with a Cre-expressing vector, e.g., transiently expressing Cre recombinase, to remove the floxed selection marker.

[00147] To generate transgenic animals, positive ES cell clones, e.g., without floxed selection marker, containing a human *DPP4* gene or fragment thereof, are introduced into a rodent embryo, e.g., a mouse or rat embryo, such as an 8-cell stage mouse embryo. For example, the introduction step is done by blastocyst injection technology, aggregation techniques, nuclear transfer and cloning, and/or the VelociMouse® method. See, e.g., US 8,759,105 B2, US 7,294,754, US 7,576,259, and US 7,659,442. For example, an ES cell clone is a subpopulation of cells derived from a single cell of the ES cell population following introduction of DNA and subsequent selection.

[00148] In some cases, DNA from transgenic non-human animals are screened in similar ways as described above to confirm transmittance of the human *DPP4* gene/fragment through the germline.

[00149] In some embodiments, the humanized *DPP4* rodents described herein are heterozygous for the human *DPP4* allele. As such, these rodents have one human *DPP4* allele and one wild-type rodent *DPP4* allele. In other embodiments, the humanized *DPP4* rodents are homozygous for the human *DPP4* allele.

Uses for Humanized DPP4 Rodents

[00150] Humanized *DPP4* rodents, e.g., mice or rats, are useful to evaluate the pharmacodynamics (PD) of human-specific DPP4 antagonists, e.g., small molecule, peptide or biologic inhibitors, useful for the treatment of hyperglycemia.

[00151] Pharmacokinetics (PK) and PD assays in humanized *DPP4* rodents, e.g., mice or rats, are performed according to standard procedures known in the art.

[00152] Humanized *DPP4* rodents, e.g., mice or rats, are useful to evaluate the *in vivo* therapeutic efficacy of human-specific DPP4 antagonists, e.g., small molecule, peptide or biologic inhibitors, in the treatment of hyperglycemia.

[00153] Humanized *DPP4* rodents, e.g., mice or rats, are useful to test the *in vivo* therapeutic efficacy of antagonists, e.g., small molecule, peptide or biologic inhibitors, e.g., neutralizing antibodies, that are specific for target molecules, e.g., MERS-CoV (e.g., spike protein (S) of MERS-CoV, e.g., receptor binding domain of the spike protein of MERS-CoV), which specifically interact with human DPP4, in the treatment or prevention (or prophylaxis) of MERS-CoV infection. In some embodiments, rodents that are heterozygous for the human *DPP4* allele are used to test the *in vivo* therapeutic

efficacy of one or more antagonists in the treatment or prevention (or prophylaxis) of MERS-CoV infection. In other embodiments, *DPP4* rodents that are homozygous for the human *DPP4* allele are used to test the *in vivo* therapeutic efficacy of one or more antagonists in the treatment or prevention (or prophylaxis) of MERS-CoV infection.

[00154] Exemplary MERS-CoV strains include MERS-CoV Jordan strain (GenBank accession no. KC776174.1, MERS-CoV- Hu/Jordan-N3/2012) and MERS-CoV EMC/2012 strain (GenBank accession no. JX869059.2). In some embodiments, a MERS-CoV virus described herein comprises a MERS-CoV clinical isolate. In other embodiments, a MERS-CoV virus described herein comprises a strain comprising the same spike protein receptor binding domain (RBD) sequence as a clinical isolate described herein. Exemplary clinical isolates are shown in the table below. The table shows the amino acid sequence variation within the receptor binding domain (RBD) of the spike protein of several MERS-CoV clinical isolates. National Center for Biotechnology Information (NCBI)-deposited sequences of MERS-CoV clinical isolates were aligned at amino acids 367-606 and compared to that of the EMC/2012 strain. Clinical isolates harboring the A431P, S457G, S460F, A482V, L506F, D509G, and V534A substitutions (where the amino acid (single letter designation) preceding the number is that of the EMC/2012 strain, and the amino acid (single letter designation) following the number is that of the clinical isolate) are shown in the table.

Table I

No variation from EMC/2012 sequence	A431P	S457G	S460F	A482V	L506F	D509G	V534A
Al-Hasa_1 Al-Hasa_2 Al-Hasa_3 Al-Hasa_4 Al-Hasa_12 Al-Hasa_15 Al-Hasa_16 Al-Hasa_17 Al-Hasa_18 Al-Hasa_19 Al-Hasa_21 Al-Hasa_25 Buraidah_1 EMC/2012 FRA/UAE Hafr-Al-Batin_1 Hafr-Al-Batin_2 Hafr-Al-Batin_6 Jeddah_1 Jordan-N3/2012 Munich Riyadh_3 Riyadh_4 Riyadh_5 Riyadh_14 Taif_1 Wadi-Ad-Dawasir_1	Riyadh_9	KFU-HKU 1 KFU-HKU 13	Qatar3 Qatar4	Riyadh_9	England 1 England-Qatar/2012	Bisha_1 Riyadh_1	Riyadh_2

[00155] In some embodiments, an antagonist is administered before (e.g., at least 1, 2, 4, 6, 12, 24, 48 hours, 2, 3, 4, 5, 6, or 7 days, or more before) a MERS-CoV infection in the rodent. In other embodiments, the antagonist is administered after (e.g., at least 1, 2, 4, 6, 12, 24, 48 hours, 2, 3, 4, 5, 6, or 7 days, or more after) a MERS-CoV infection in the rodent.

[00156] In some embodiments, where an antagonist is administered to a rodent after MERS-CoV infection, a lower viral titer or RNA level (e.g., viral UpE or leader sequence RNA level) in the rodent after administration of the antagonist, e.g., lower by at least 5-fold (e.g., at least 5, 10, 50, 100, 500, 1000, 10^4 , 10^5 , 10^6 , 10^7 -fold or more) compared to a control level indicates that the antagonist is effective in treating a MERS-CoV infection. For example, a control level is the viral titer or RNA level in the rodent prior to administration of the antagonist. In other examples, a control level is the viral titer or RNA level in a virus-infected rodent that is untreated with the antagonist.

[00157] In some embodiments, where an antagonist is administered to a rodent prior to MERS-CoV infection, a lower viral titer or RNA level (e.g., viral UpE or leader sequence RNA level) in the rodent after administration of the antagonist, e.g., lower by at least 5-fold (e.g., at least 5, 10, 50, 100, 500, 1000, 10^4 , 10^5 , 10^6 , 10^7 -fold or more) compared to a control level indicates that the antagonist is effective in preventing a MERS-CoV infection. For example, a control level is the viral titer or RNA level of a rodent infected with MERS-CoV that was not treated with the antagonist.

[00158] In some embodiments, viral RNA levels in a rodent lung can be determined by extracting RNA from the rodent lung by homogenization in a solution containing phenol, e.g., a solution containing phenol and guanidinium isothiocyanate (e.g., Trizol® (Life Technologies, Inc)). For example, the lung can be homogenized using a Magnalyzer (Roche) according to the manufacturers' instructions. In some embodiments, levels of MERS-CoV RNA can be assessed using quantitative PCR (qPCR) using primers that target the MERS-CoV genome and/or primers that target the MERS-CoV mRNA transcript. For example, the Taqman® Fast virus one-step master mix (Applied Biosystems) can be used in qPCR according to the manufacturers' instructions using a duplex of primers obtained from Life Technologies targeting a region of the genome upstream of the envelope gene (UpE) or the leader sequence of the nucleocapsid messenger RNA (leader primer), and compared to an endogenous control, such as rodent (e.g., mouse) 18S rRNA. For example, qPCR reactions in Microamp® fast optical reaction plates (Applied Biosystems) can be read on a 7500 fast DX real-time PCR instrument (Applied Biosystems). In some examples, qPCR data can be analyzed using the delta Ct method, with an uninfected control set to 1. For example, percent MERS-CoV RNA detected can be expressed relative to levels of RNA detected in infected mice treated with control antagonist, e.g., isotype-matched control antibodies, in cases where the antagonist is an antibody against MERS-CoV.

[00159] In some embodiments, the viral titer in a rodent lung can be determined by homogenizing the rodent lung in a buffer (e.g., phosphate buffered saline (PBS)), centrifuged (e.g., at 10,000 rpm). The supernatant can be analyzed by plaque assay on mammalian cells, such as Vero cells (e.g., Vero E6 cells) to quantitate levels of virus remaining after treatment with an antagonist. A standard plaque assay can be used, e.g., a plaque assay described in Page et al. (2012) Induction of alternatively activated macrophages enhances pathogenesis during severe acute respiratory syndrome

coronavirus infection, *J Virol* 86:13334–13349. In some examples, the Page et al. plaque assay can be modified by leaving plates for 3 days for plaques to appear.

[00160] In some embodiments, less inflammation (e.g., interstitial or peri-vascular inflammation), fewer inflammatory cells, and/or less bronchiolar cuffing, e.g., determined by histological analysis, in a lung sample of a rodent treated with an antagonist prior to or after MERS-CoV infection compared to a control lung sample can indicate that the antagonist is effective in treating or preventing a MERS-CoV infection. For example, a control lung sample can be from a rodent infected with MERS-CoV that is untreated with an antagonist, e.g., untreated before and/or after infection.

[00161] The rodents described herein are useful for the efficient testing of drugs and vaccines for MERS-CoV, e.g., to demonstrate safety and efficacy prior to clinical testing in humans. They permit rapid identification and/or validation of therapeutics/prophylactics, e.g., within several weeks of testing.

Definitions

[00162] Homologous amino acid residues are residues that share similar characteristics or properties. Characteristics or properties of an amino acid residue are based on, e.g., the structure of the polypeptide backbone, for example, a sheet or helical conformation, the charge or hydrophobicity of the residue, and/or the bulk of the side chain(s). For example, homologous residues are similar in side chain properties, e.g., polarity, charge, size, aromaticity, and/or hydrophobicity.

[00163] The term, “about” refers to a stated value plus or minus another amount; thereby establishing a range of values. In certain embodiments, “about” indicates a range relative to a base (or core or reference) value or amount plus or minus up to 15%, 14%, 13%, 12%, 11%, 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.75%, 0.5%, 0.25% or 0.1%. For example, about refers to a range of +/- 5% below and above the recited numbers, e.g., numbers of nucleotide bases.

[00164] The term “operably linked” as used herein refers to positions of components so described, e.g., nucleotide sequences, are in a relationship permitting them to function in their intended manner.

[00165] As used herein, the term “protein” includes polypeptides, peptides, fragments of polypeptides, and fusion polypeptides.

[00166] As used herein, a “nucleic acid” refers to two or more deoxyribonucleotides and/or ribonucleotides covalently joined together in either single or double-stranded form.

[00167] The term “replacement” in reference to gene replacement refers to placing exogenous genetic material at an endogenous genetic locus, thereby replacing all or a portion of the endogenous gene with an orthologous or homologous nucleic acid sequence. In one instance, an endogenous non-human gene or fragment thereof is replaced with a corresponding human gene or fragment thereof. A corresponding human gene or fragment thereof is a human gene or fragment that is an ortholog of, a homolog of, or is substantially identical or the same in structure and/or function, as the endogenous non-human gene or fragment thereof that is replaced.

[00168] As used herein, the term “rodent” refers to any member of the order Rodentia. Examples of rodents include, without limitation, mice, rats, squirrels, prairie dogs, porcupines, beavers, guinea pigs, and hamsters. In one embodiment, a rodent is a rat. In another embodiment, a rodent is a mouse.

[00169] Unless defined otherwise herein, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention pertains.

[00170] As used herein, the singular terms “a,” “an,” and “the” include the plural reference unless the context clearly indicates otherwise.

[00171] It is intended that every maximum numerical limitation given throughout this specification includes every lower numerical limitation, as if such lower numerical limitations were expressly written herein. Every minimum numerical limitation given throughout this specification will include every higher numerical limitation, as if such higher numerical limitations were expressly written herein. Every numerical range given throughout this specification will include every narrower numerical range that falls within such broader numerical range, as if such narrower numerical ranges were all expressly written herein.

[00172] The following examples are provided for illustrative purposes only and not intended to limit the invention in any manner.

EXAMPLES

Example 1

Replacement of the Endogenous Mouse *Dpp4* Gene With a Human *DPP4* Gene

[00173] The 81.8 kb human *DPP4* gene containing exon 2 through exon 26 and a portion of the 3' untranslated region of the human *DPP4* gene replaced 78.8 kb of the murine *Dpp4* gene locus spanning exon 2 through the stop codon in exon 26. See **Figures 1A and 1B**.

[00174] A targeting construct for replacing the mouse with the human *DPP4* gene in a single targeting step was constructed using VelociGene® genetic engineering technology (see Valenzuela et al. (2003) High-throughput engineering of the mouse genome coupled with high-resolution expression analysis, Nature Biotech, 21(6):652-659). Mouse and human *DPP4* DNA were obtained from bacterial artificial chromosome (BAC) clones RP23-362N15 and RP11-68L22, respectively. Briefly, an SgrDI linearized targeting construct generated by gap repair cloning containing mouse *Dpp4* upstream and downstream homology arms flanking 82 kb of human *DPP4* sequence extending from intron 1 upstream of exon 2 through exon 26, including the stop codon and a portion of the 3' untranslated region (genomic coordinates of the entire human *DPP4* gene: GRCh38: chr2:162,848,755-162,931,052 (- strand)), and a floxed neo selection cassette, was electroporated into VGB6 mouse embryonic stem (ES) cells (derived from C57BL/6N mice). Correctly targeted ES cells (MAID 7326) were further electroporated with a transient Cre-expressing vector to remove the drug selection cassette. Targeted ES cell clones without drug cassette (MAID 7327) were introduced into an 8-cell stage SW mouse embryo by the VelociMouse® method (see, U.S. Pat. Nos. 7,294,754, 7,576,259, 7,659,442, and Poueymirou et al. (2007) F0 generation mice that are essentially fully derived from the donor gene-targeted ES cells allowing immediate phenotypic analyses Nature Biotech. 25(1):91-99). VelociMice® (F0 mice fully derived from the donor ES cell) bearing the humanized *DPP4* gene were identified by genotyping for loss of mouse allele and gain of human allele using a modification of allele assay (see, Valenzuela et al. (2003)).

[00175] Correctly targeted ES cell clones were identified by a loss-of-native-allele (LONA) assay (Valenzuela et al. 2003) in which the number of copies of the native, unmodified *Dpp4* gene were determined by two TaqMan™ quantitative polymerase

chain reactions (qPCRs) specific for sequences in the mouse *Dpp4* gene that were targeted for deletion. The qPCR assays comprised the following primer-probe sets (written 5' to 3'): upstream forward primer, TCGCCACTGT GCCTAACATA G (SEQ ID NO:1); upstream reverse primer, CCGGGACTAA ACTGGAACAT TC (SEQ ID NO:2); upstream probe, FAM-TCAGTCAACT TCTTCTGGGT TGTTCCTC-BHQ (SEQ ID NO:3); downstream forward primer, CAGCTCTGGT GGAGAACTAG AC (SEQ ID NO:4); downstream reverse primer, GGAGGTCCTC GGTCTTTAGA AG (SEQ ID NO:5); downstream probe, FAM-TCACACTTAG GCTTATAAAC CATTCCCGT-BHQ (SEQ ID NO:6); in which FAM refers to the 5-carboxyfluorescein fluorescent probe and BHQ refers to the fluorescence quencher of the black hole quencher type (Biosearch Technologies). DNA purified from ES cell clones that have taken up the targeting vector and incorporated in their genomes was combined with TaqMan™ Gene Expression Master Mix (Life Technologies) according to the manufacturer's suggestions in a 384-well PCR plate (MicroAmp™ Optical 384-Well Reaction Plate, Life Technologies) and cycled in an Applied Biosystems Prism 7900HT, which collects fluorescence data during the course of the PCRs and determines a threshold cycle (Ct), the fractional PCR cycle at which the accumulated fluorescence reaches a pre-set threshold. The upstream and downstream *DPP4*-specific qPCRs and two qPCRs for non-targeted reference genes were run for each DNA sample. The differences in the Ct values (ΔCt) between each *DPP4*-specific qPCR and each reference gene qPCR were calculated, and then the difference between each ΔCt and the median ΔCt for all samples assayed was calculated to obtain $\Delta\Delta Ct$ values for each sample. The copy number of the *DPP4* gene in each sample was calculated from the following formula: $\text{copy number} = 2^{2 - \Delta\Delta Ct}$. A correctly targeted clone, having lost one of its native copies, will have a *Dpp4* gene copy number equal to one. Confirmation that the human *DPP4* gene sequence replaced the deleted mouse *Dpp4* gene sequence in the humanized allele was confirmed by a TaqMan™ qPCR assay that comprises the following primer-probe sets (written 5' to 3'): human upstream forward primer, GCGGTCTCCC TCTTCTAACG (SEQ ID NO:7); human upstream reverse primer, GCAAGCCGAG CAGATCAAG (SEQ ID NO:8); human upstream probe, FAM-ACTCCACCT GCAAATCCTG CTGC-BHQ (SEQ ID NO:9); human downstream forward primer, AACCGCACTG GCATATGGA (SEQ ID NO:10); human downstream reverse primer, TACAAGGTAG TCTGGGATTA CTAACAAAA (SEQ ID NO:11); human downstream probe, FAM-ACATTTATCT AGAAAGGCTC-BHQ (SEQ ID NO:12).

[00176] The same LONA assay is used to assay DNA purified from tail biopsies for mice derived from the targeted ES cells to determine their *DPP4* genotypes and confirm that the humanized *DPP4* allele is transmitted through the germline. Two pups heterozygous for the replacement are bred to generate a mouse that is homozygous for the replacement of the endogenous mouse *Dpp4* gene by the human *DPP4* gene. Pups that are homozygous for the replacement are used for phenotyping.

[00177] The upstream junction of the murine *Dpp4* locus and the sequence containing the human *DPP4* gene is designed to be within 5'-AGGAGAGAAG CCAACAAGAT CATAAGATCA TGCTCAGGGC CAAAATTCAA GGGCTTCTGC (CGTCGACG) *GCCTTAGAGA ACTCCAACCTG GCGCACTCCA GACGCCACCC CCACCCCCAG CCCGCGGTCT CCCTCTTCTA ACGCACTCCC ACCTGCAAAT* (SEQ ID NO:13), wherein the human *DPP4* sequences are italicized, and the SgrDI restriction site is bracketed. The downstream junction of the sequence containing the human *DPP4* gene and the floxed neo selection cassette is designed to be within 5'-*TTATTCCAGG GAACTATGAT GAGGCTTATA TAAGAACGAA TAAGATCAGA AATATCATTC TGGCAGTTCT TATGGCTCAG* ctcgag(ataa cttcgataa tgtatgctat acgaagtat) atgcatggcc tccgcgccgg gtttggcgc ctcccgcggg (SEQ ID NO:14), wherein the human *DPP4* sequences are italicized, the neo cassette sequences are in lower case, and the loxP site is bracketed. The downstream junction of the sequence of the floxed neo selection cassette and the murine *Dpp4* locus is designed to be within 5'-atgtctgga(a taacttcgta taatgtatgc tatacgaagt tat)gctagta actataacgg tcctaaggta gcgagctagc CAGCATAGCT CTCCATAGCT TATTTAAGAC CACATTTGTT CTCATTATCT CAAAAGTGCA CTGTTAAGAT GAAGATCTTA (SEQ ID NO:15), wherein the neo cassette sequences are in lower case, and the loxP site is bracketed. After removal of the neo selection cassette, the junction of the sequence containing the human *DPP4* gene, the loxP site remaining after removal of the neo selection cassette, and the murine *Dpp4* locus is designed to be within 5'- *TATTCCAGGG AACTATGATG AGGCTTATAT AAGAACGAAT AAGATCAGAA ATATCATTC TGGCAGTTCTT ATGGCTCAG* ctcgag(ataa cttcgataa tgtatgctat acgaagtat) gctagtaact ataacggtcc taagtagcg agctagcCA GCATAGCTCT CCATAGCTTA TTTAAGACCA CATTTGTTCT CATTATCTCA AAAGTGCACT GTTAAGATGA AGATCTTAAT AATGTTGCAT TGAGACATTT CAGGCTGCTT TCTCCAGTTT TACACCTGCA ATCCTAACTA AGGATGCCTG TCCCCAGAAC (SEQ ID NO:16), wherein the human *DPP4* sequences are italicized, the neo cassette sequences are in lower case, and the loxP site is bracketed.

[00178] **Figure 2** shows the amino acid sequence of *DPP4* encoded by the humanized *DPP4* nucleic sequence in MAID 7326/7327 (SEQ ID NO:17) is the same as human *DPP4* because mouse *Dpp4* codon 1, encodes only the first two amino acids of *DPP4*, Met and Lys, which are the same as those encoded by human *DPP4* codon 1.

Example 2

Infection of Humanized *DPP4* Mice by MERS-CoV

[00179] Middle East Respiratory Syndrome – Coronavirus (MERS-CoV) is a newly emergent virus that causes severe acute respiratory disease. The receptor for MERS-CoV is dipeptidyl peptidase IV (DPP4) (see Raj et al. (2013) Dipeptidyl Peptidase 4 is a Functional Receptor for the Emerging Human Coronavirus-EMC, *Nature* 495(7440):251-254). *In vivo* testing of anti-viral molecules requires an animal model, e.g., a small animal model, such as a rodent (e.g., mouse or rat), that is susceptible to MERS-CoV infection. However, recent studies have shown that mouse *Dpp4* cannot support MERS-CoV infection (see, e.g., Cockrell et al. (2014) Mouse Dipeptidyl Peptidase is Not a Functional Receptor for Middle East Respiratory Syndrome Coronavirus (MERS-CoV) Infection, *J. Virol.* 88(9):5195-5199; and Coleman et al. (2014) Wild-Type and Innate Immune-Deficient Mice are Not Susceptible to the Middle East Respiratory Syndrome Coronavirus, *J. Gen. Virol.* 95(2):408-412), at least in part because the MERS-CoV Spike protein interacts with human, but not mouse, DPP4 (see, e.g., Coleman et al. (2013); and Raj et al. (2013)). Sequence comparison of the sequences of mouse and human DPP4 revealed that the amino acids that have previously been identified as contact sites between MERS-CoV spike (S) protein and its receptor differ between the two species. In addition, expression of human DPP4 in mouse cells allows for MERS-CoV virus entry and propagation, indicating that entry of the virus is the limiting step in infection of mouse cells, and that the lack of interaction between mouse DPP4 and the MERS-CoV glycoprotein defines the species tropism *in vitro*. See, e.g., Lu et al. (2013) Molecular basis of binding between novel human coronavirus MERS-CoV and its receptor CD26, *Nature*. 500(7461):227-31; and Cockrell et al. (2014) Mouse Dipeptidyl Peptidase is Not a Functional Receptor for Middle East Respiratory Syndrome Coronavirus (MERS-CoV) Infection, *J. Virol.* 88(9):5195-5199.

[00180] As a consequence, normal mouse strains cannot be used to measure the efficacy of therapeutics targeting MERS-CoV. Zhao et al. (2014) Rapid Generation of a Mouse Model for Middle East Respiratory Syndrome, Proc. Natl. Acad. Sci. USA 111(13):4970-4975 have expressed human DPP4 in mice by adenovirus transduction, thereby allowing for MERS-CoV infection. However, this adenovirus model has several limitations, including: (a) the virus is cleared rapidly from infected mice; (b) there is a loss of human DPP4 expression over time; (c) the tissue distribution of virally-transduced DPP4 does not reflect expression seen in mice or humans; and (d) adenovirus infection induces an interferon response.

[00181] To generate a mouse model for MERS-CoV infection, humanized *DPP4* mice were generated as described above in Example 1. As shown in **Figure 1B**, exons 2 through 26 of mouse *Dpp4* were replaced by the corresponding sequences of human *DPP4*. Because the remaining mouse *Dpp4* coding exon 1 encodes only the first two amino acids of Dpp4, Met and Lys, which are the same as those in corresponding human *DPP4* exon 1, the DPP4 protein expressed in humanized *DPP4* mice is completely human (see **Figure 2**, SEQ ID NO:17). Thus, humanized *DPP4* mice express a fully human DPP4 under the control of the endogenous mouse regulatory sequences, i.e., 5' flanking region (promoter and enhancer(s)), and 3' untranslated region sequences. It is expected that the humanized DPP4 is expressed in the same cells and tissues, and at the same or similar levels, as mouse Dpp4 is expressed in wild-type mice lacking human *DPP4* nucleic acid sequences.

[00182] Two F0 humanized *DPP4* mice were infected intranasally with MERS-CoV (Jordan strain) or mock treated with PBS. Four days post-infection, MERS-CoV RNA was quantified in the lungs by real-time PCR using primers specific for the replicative form of the MERS-CoV genome. Data was normalized to the amount of PCR product obtained from the lungs of the mock-infected mice (arbitrarily set at 1). **Figure 3** shows that MERS-CoV RNA could be amplified from lungs of the MERS-CoV-infected humanized *DPP4* mice. H&E staining was also performed using lung tissue from mock- and MERS-CoV-infected mice. **Figure 4** shows that MERS-CoV infection of humanized *DPP4* mice did not affect the airway, but resulted in thickening of the walls of the alveoli and less space between alveolar cells, indicating inflammation in the lungs associated with MERS-CoV infection.

[00183] In addition, 6 to 8 week old mice were inoculated intranasally with MERS-CoV, e.g., 2×10^5 pfu of MERS-CoV (Jordan). No mortality or clinical signs of disease were observed up to day 4 after inoculation. On days 2 and 4 post-inoculation, mice were euthanized and their lungs were dissected. To obtain virus RNA levels, lungs were homogenized in Trizol®, RNA extracted, and analyzed by real-time PCR using primers specific to MERS-CoV (**Figures 10A and 10B**). A set of primers was specific to a region of the viral genome upstream of the envelope gene (UpE), and another set of primers was specific to the leader sequence of the nucleocapsid mRNA (leader primer). Mouse 18S rRNA was used as endogenous control.

[00184] To obtain virus titers, lungs were homogenized in phosphate buffered saline (PBS), clarified by centrifugation, and titered on Vero E6 cells (**Figure 10C**). For example, the supernatant was analyzed by a plaque assay on VeroE6 cells to quantitate the levels of virus present in the lungs. For example, plaque assays were performed as described in Page et al. (2012) Induction of alternatively activated macrophages enhances pathogenesis during severe acute respiratory syndrome coronavirus infection, *J Virol* 86:13334–13349, with plates left for 3 days for plaques to appear.

[00185] Robust MERS-CoV replication in the lungs was evident at 2 and 4 days post-infection. RNA quantification, using a primer set specific for MERS-CoV leader, which was designed to only amplify replicating MERS-CoV, demonstrated high levels of MERS-CoV replicating RNA in lungs collected at day 2, and these levels were maintained through day 4 post-infection (**Figures 10A-B**). Plaque assay of lung homogenate on Vero E6 cells quantified MERS-CoV (Jordan) levels of $\sim 7.27 \times 10^4$ pfu/mL lung at day 2 and $\sim 3.75 \times 10^5$ pfu/mL lung at 4 days post-infection (**Figure 10C**), demonstrating active replication of MERS-CoV in the lungs of the infected humanized *DPP4* mice.

[00186] Also, lungs from humanized *DPP4* mice intranasally inoculated with either MERS-CoV (Jordan strain) or PBS (mock infected) were analyzed for pathological changes (**Figure 10D**). At day 2 post-infection, peri-bronchiolar inflammation was evident with alterations in bronchiolar cell structure found throughout the lungs. Minimal peri-vascular inflammation or effects on alveolar structures were observed at this time point. At 4 days post-infection, interstitial infiltration was observed with peri-vascular cuffing and extensive alveolar thickening. Bronchiolar alterations were present as well. See **Figure 10D**. This pathology is consistent with the radiographic

findings of development of interstitial pneumonia and significant lung disease seen in humans with MERS-CoV.

[00187] The above data shows that humanized *DPP4* mice, such as those described herein, are susceptible to MERS-CoV infection. The data also demonstrate that the humanized *DPP4* mice described herein are an *in vivo* model of MERS-CoV infection that recapitulates the pathology, e.g., pathological sequelae, that is seen in MERS-CoV infection of humans.

[00188] Thus, humanized *DPP4* mice are a robust model of MERS-CoV that is useful to assess MERS-CoV treatment *in vivo*. For example, the humanized *DPP4* mice are appropriate host animals to measure the pharmacokinetics, pharmacodynamics and therapeutic efficacy of therapeutic molecules that target MERS-CoV.

[00189] **Figure 5** shows a protein sequence alignment of mouse *Dpp4* (SEQ ID NO: 25) and human *DPP4* (encoded by the 7326/7327 transgenic mice) (SEQ ID NO: 26).

[00190] Next, a dose-response study of weight as a function of time post-infection of MERS-CoV was conducted in humanized *DPP4* mice. Mice were infected with either MERS-CoV (Jordan strain) or PBS (mock infected) as described above and were analyzed for weight loss, which is a sign of productive infection, over a period of seven days. As shown in **Figure 14**, humanized *DPP4* mice exhibited productive infection (i.e., manifested disease pathology), with weight loss beginning 4 days post-infection. Four to five mice were used per group. **Figure 15** shows that mice that were heterozygotic for the humanized *DPP4* allele were equally susceptible to infection by MERS-CoV, as they exhibited a similar degree of weight loss when compared to homozygotes. This finding is significant because it indicates that studies can be conducted using heterozygous mice. Additionally, use of heterozygous mice avoids any potential issue related to functional mouse *Dpp4* knockouts that could potentially be present in homozygous humanized *DPP4* mice.

[00191] The lungs of these mice were also examined histologically for inflammation according to the methods described above. As shown in **Figure 16**, h*DPP4* mice exposed to a high dose of virus (1×10^6 pfu/mouse) exhibited increased pathology relative to PBS controls.

Example 3

Generation of Transgenic Mice Containing the Human *DPP4* Gene using Random Insertion of BACs

[00192] Transgenic mice were generated that contain the human *DPP4* gene, for which the sequence and genomic information is shown in **Figure 6**. Two different overlapping BACs containing the human *DPP4* gene were used: BAC RP11-68L22 and BAC RP11-345J9 (**Figure 7**). Both BACs contained the coding region of the human *DPP4* gene, as well as over 40 kb of promoter region upstream of the ATG start codon of the *DPP4* gene and several kilobases downstream of the stop codon of the *DPP4* gene (**Figure 7**).

[00193] To generate the BAC transgenic mice, each BAC DNA was electroporated into VGB6 mouse embryonic stem (ES) cells (derived from C57BL/6N mice). ES cells containing the coding region of the human *DPP4* gene, as well as promoter regions of the gene, were introduced into an 8-cell stage SW mouse embryo by the SW mouse embryo by the VelociMouse® method (see, e.g., U.S. Pat. Nos. 7,294,754, 7,576,259, 7,659,442, and Poueymirou et al. (2007) F0 generation mice that are essentially fully derived from the donor gene-targeted ES cells allowing immediate phenotypic analyses Nature Biotech. 25(1):91-99).

[00194] Human gain of allele assays were used to screen ES cell clones for ones that contained copies of the human *DPP4* gene along with promoter regions of the gene. Human gain of allele assays were also used to identify VelociMice® (F0 mice fully derived from the donor ES cell) bearing the humanized *DPP4* gene along with promoter regions of the gene.

[00195] Briefly, genomic DNA was extracted from ES cell clones using standard methods and tested in a TaqMan™ quantitative PCR (qPCR) assay using two sets of primer-probes to detect a human DNA sequence upstream (7333 hTU) and downstream (7333 hTD) of the human *DPP4* coding sequence (**Figure 8**). The locations within the human *DPP4* gene and flanking regions (e.g., promoter regions) at which each primer-probe set annealed is shown in **Figure 7**. A fluorescent read-out above background in the TaqMan™ qPCR assay indicated the presence of the human *DPP4* gene and at least 40 kb of the 5' flanking region of the human *DPP4* gene that had been integrated into the transgenic mouse genome.

[00196] The 7333 hTU primer-probe set (written 5' to 3') was: human upstream forward primer, TGGCTTATTCTCTATTCCTCACCTA (SEQ ID NO: 18); human upstream probe, FAM-TGCTTTCCCTCCTCCCTTCTGA-BHQ (SEQ ID NO: 19); human upstream reverse primer, GGCCTTAGCCCAGAACTG (SEQ ID NO: 20). The 7333 hTD primer-probe set (written 5' to 3') was: human downstream forward primer, TGCAGACTTGCTTGACATTCATA (SEQ ID NO: 21); human downstream probe, CAL-AGCCTCTGCAGACACAGGAATGGC-BHQ (SEQ ID NO: 22); and human downstream reverse primer, TCTGGGCACTGGTGTACTC (SEQ ID NO: 23); in which FAM and CAL refer to the 5-carboxyfluorescein and CAL Orange fluorescent probes, respectively, and BHQ refers to the fluorescence quencher of the black hole quencher type (Biosearch Technologies).

[00197] For example, genomic DNA from ES cell clones was combined with TaqMan™ Gene Expression Master Mix (Life Technologies) according to the manufacturer's suggestions in a 384-well PCR plate (MicroAmp™ Optical 384-Well Reaction Plate, Life Technologies) and cycled in an Applied Biosystems Prism 7900HT, which collects fluorescence data during the course of the PCRs and determines a threshold cycle (Ct), the fractional PCR cycle at which the accumulated fluorescence reaches a pre-set threshold. The upstream and downstream DPP4-specific qPCRs and two qPCRs for non-DPP4 reference genes were run for each DNA sample. The differences in the Ct values (ΔCt) between each DPP4-specific qPCR and each reference gene qPCR were calculated, and then the difference between each ΔCt and the median ΔCt for all samples assayed was calculated to obtain $\Delta\Delta Ct$ values for each sample. The copy number of the *DPP4* gene in each sample was calculated from the following formula: $\text{copy number} = 2^{2^{-\Delta\Delta Ct}}$. A clone containing at least one copy of the human *DPP4* plus promoter regions integrated into the chromosome had a *DPP4* gene copy number equal to or greater than one.

[00198] The same human gain of allele assay was used to assay DNA purified from tail biopsies for mice derived from the ES cells to confirm that the humanized *DPP4* allele along with the human 5' flanking regions were transmitted through the germline.

[00199] Using the BAC insertion and screening methods described herein, two transgenic mice with DNA encoding human DPP4 were confirmed. BAC RP11-68L22 was used to generate ES cell clones and transgenic mice referred to as MAID 7333, and

BAC RP11-345J9 was used to generate ES cell clones and transgenic mice referred to as MAID 7334.

[00200] The protein encoded by the humanized *DPP4* nucleic acid sequence in the MAID 7333 and 7334 mice had the amino acid sequence shown in **Figure 9** (SEQ ID NO: 24), which is the same as human DPP4 (as encoded by the transcript, NM_001935.3).

Example 4

Treatment of Humanized *DPP4* Mice that were infected with the MERS-CoV virus

[00201] Transgenic mice with the humanized *DPP4* gene and flanking promoter regions were tested for their ability to be infected by MERS-CoV and to serve as a model for assessing therapeutic molecules for treating or preventing MERS-CoV.

[00202] Transgenic MAID 7333 mice (e.g., generated by the methods described in Example 3) were treated with 200 µg of antibodies directed against MERS-CoV spike protein or isotype controls by intraperitoneal injection (ip). One day after antibody injection, the mice were infected intranasally with MERS-CoV. Four days after infection, lungs of the mice were harvested, and viral RNA levels were measured using real-time PCR (RT-PCR). In particular, levels of the genomic RNA (UpE) or replicating RNA (leader) (specific for the replicative form of the MERS-CoV genome) of MERS-CoV were measured.

[00203] The RT-PCR data is shown in the table below.

Antibody	UpE ¹	Leader ¹
Anti-MERS-CoV spike protein 1 (Ab 1)	0.356839562	0.273565089
Anti-MERS-CoV spike protein 2 (Ab 2)	0.254493202	0.206006238
Anti-MERS-CoV spike protein 3 (Ab 3)	1.989548316	1.112094283
(IgG1) isotype control	104.0889287	101.2578723
(IgG4) isotype control	100	100

¹Averages (% of isotype control)

[00204] Treatment of transgenic mice with the antibodies decreased viral RNA levels (both UpE and Leader) by about 50-fold to about 500-fold.

[00205] The data described herein show that transgenic mice generated by targeted integration methods (Example 1) and random BAC insertion methods (Example 3) with human *DPP4* were susceptible to infection by MERS-CoV. In addition, anti-MERS-CoV antibodies blocked infection in transgenic mice *in vivo*. Thus, transgenic mice with human DPP4 (e.g., generated by the methods described herein) are useful for evaluating the efficacy of therapeutics (e.g., antibodies) that target the MERS-CoV virus.

Example 5

Prophylactic effects of anti-MERS-CoV antibodies on MERS-CoV infection in humanized *DPP4* mice

[00206] The humanized *DPP4* mice described herein were used to evaluate the prophylactic capability of the two monoclonal antibodies *in vivo*. Mice were i.p. injected with a dose range of anti-MERS-CoV antibodies—200 µg, 20 µg or 2 µg of anti-MERS-CoV spike protein antibody 2 (Ab 2), anti-MERS-CoV spike protein antibody 4 (Ab 4), or 200 µg of human IgG1 (hIgG1) isotype control antibody—at 24 hours before intranasal infection with 1×10^5 pfu of MERS-CoV (Jordan strain). Ab 2 and Ab 4 were fully human anti-MERS-CoV spike protein antibodies. RNA was extracted from the mouse lungs and analyzed by quantitative PCR as described above. For example, qPCR data was analyzed using the delta Ct method, with an uninfected control set to 1. Percent MERS-CoV RNA detected was expressed relative to levels of RNA detected in infected mice treated with isotype-matched control antibodies (**Figures 11A-B**). Also, viral titers from mouse lungs were determined as described above.

[00207] Both antibodies significantly decreased MERS-CoV specific RNA levels in the lungs by over 2 logs at the 200 µg per mouse dose, compared to the isotype-matched control antibody (**Figures 11A-B**). Ab 2 was more effective at reducing MERS-CoV RNA levels at the 20 µg dose compared to Ab 4 at the same dose. The 2 µg dosing of either antibody was ineffective at reducing viral RNA levels compared to isotype control treated mice. When MERS-CoV titer was analyzed in the lungs (**Figure 11C**), both the 200 µg and 20 µg dose of Ab 2 reduced virus levels to near the level of detection in the assay (2×10^3 pfu/ml). Ab 4 was equally efficient at the 200 µg dose as Ab 2, while the 20 µg and 2 µg doses displayed a dose dependent inhibition of viral inhibition. These data show that anti-MERS-CoV antibodies, e.g., Ab 2 and Ab 4, effectively blocked MERS-CoV infection *in vivo*.

[00208] Histological analysis was also performed at 4 days post-infection on lungs from mice treated at 24 hours pre-infection with Ab 2, Ab 4, or hIgG1 isotype control antibody (**Figure 12A**). For example, the degrees of interstitial, peribronchiolar, and perivascular inflammation were scored from 0 to 5. Other histologic features, such as the presence of bronchiolar epithelial and alveolar damage, pleural changes and the extent of peribronchovascular inflammation, were also analyzed. An overall inflammatory score for each mouse was averaged for each experimental group, and the scores were presented as average scores of all mice in each group and time point (**Figure 12B**).

[00209] Lungs from mice pre-treated with hIgG1 isotype control mice displayed significant lung pathology with increased interstitial inflammation, perivascular cuffing, and thickening of alveolar septa. Mice treated with 200 µg of either Ab 2 or Ab 4 had reduced inflammation with minimal foci of inflammatory cells in the interstitium, minor bronchiolar cuffing, and less alveolar wall thickening. In mice pre-treated with 20 µg of Ab 2 and Ab 4, there were moderate levels of perivascular cuffing and interstitial inflammation compared to the higher dose antibody group. The 2 µg antibody pre-treated group had similar pathology to the hIgG1 isotype control, displaying significant interstitial inflammation and predominant peri-vascular inflammation. Blinded histological scoring demonstrated reduced inflammation scores for treated mice (**Figure 12B**). These findings demonstrate that anti-MERS-CoV antibodies, such as Ab 2 and Ab 4, confer a dose-dependent reduction in lung pathology following MERS-CoV infection, corroborating viral RNA levels and virus titers in the mice.

[00210] Thus, anti-MERS-CoV antibodies, such as Ab 2 and Ab 4, were effective in an *in vivo* model of MERS-CoV infection—the antibodies blocked MERS-CoV infection and disease *in vivo* when injected before infection, e.g., 1 day before infection.

Example 6

Antibody treatment of humanized *DPP4* mice that have been infected with MERS-CoV

[00211] To determine the therapeutic effect (e.g., ability to inhibit MERS-CoV replication and lung pathology after infection) of anti-MERS-CoV antibodies (e.g., Ab 2 or Ab 4), humanized *DPP4* mice were infected with MERS-CoV. At 24 hours post-infection, the mice were injected i.p. with either 500 µg of hIgG1 isotype control or Ab 2

at 500 µg or 200 µg. At 4 days post-infection, mice were euthanized and mouse lungs analyzed for viral RNA, virus titer, and lung pathology. Both the 500 µg and 200 µg doses of Ab 2 reduced viral RNA levels by about 10 fold in the lungs of mice compared to control antibody treated mice (**Figures 13A-B**). Lung titers of the same mice demonstrated significant reduction in viral levels in the lungs, with a greater than 2 log reduction at day 4 post-infection (**Figure 13C**). These data demonstrate that after infection, e.g., 24 hours post-infection, an anti-MERS-CoV antibody (e.g., Ab 2) significantly inhibited viral replication.

[00212] Histological analysis was also performed on mice treated 24 hours post-infection with hIgG1 control antibody, 500 µg Ab 2, or 200 µg Ab 2 (**Figures 14A-B**). Mice treated with control antibody displayed similar pathology to the controls in Examples 2 and 5, with significant interstitial inflammation, peri-vascular cuffing, and thickening of alveolar septa. Mice treated with either 200 µg or 500 µg of Ab 2 had minimal interstitial inflammation with reduced and only focal peri-vascular inflammation throughout the lungs. Blinded histological scoring demonstrated reduced inflammation scores for treated mice (**Figure 14B**). The data demonstrate that therapeutic doses of anti-MERS-CoV antibodies (e.g., Ab 2) reduced MERS-CoV induced lung pathology even when given after infection, e.g., 24 hours post-infection.

CLAIMS

1. A rodent, comprising a humanization of an endogenous rodent *Dpp4* gene, wherein the humanization comprises a replacement at the endogenous rodent *Dpp4* locus of a rodent gene encoding an exon of an *Dpp4* gene with a nucleic acid sequence encoding at least one exon of a human *DPP4* gene to form a modified *DPP4* gene, wherein expression of the modified *DPP4* gene is under control of rodent regulatory elements at the endogenous rodent *Dpp4* locus.
2. The rodent of claim 1, wherein the rodent is a mouse or a rat.
3. The rodent of claim 1, wherein the human *DPP4* gene encoding a human or humanized DPP4 protein comprises exon 2 through exon 26 of the human *DPP4* gene.
4. The rodent of claim 3, wherein the humanized DPP4 protein comprises the extracellular domain of the human DPP4 protein.
5. The rodent of claim 4, wherein the humanized DPP4 protein comprises the transmembrane domain and cytoplasmic domain of the mouse *Dpp4* protein.
6. The rodent of claim 1, wherein the rodent is a mouse that is incapable of expressing a mouse *Dpp4* protein.
7. The rodent of claim 1, wherein the rodent is a mouse, and wherein a contiguous genomic fragment of mouse *Dpp4* sequence encoding exon 2 through exon 26 of mouse *Dpp4* is replaced with a contiguous genomic fragment of human *DPP4* sequence encoding exon 2 through exon 26 of human *DPP4*.
8. The rodent of claim 1, wherein the rodent is a mouse that expresses human or humanized DPP4 protein on the surface of T cells, wherein the amount of T cells present

in the blood is at least about 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130%, 140%, 150%, 160%, 170%, 180%, 190% or 200% of the amount of T cells present in the blood of an age-matched mouse that expresses functional endogenous mouse Dpp4 protein, but does not comprise said replacement.

9. The rodent of claim 1, wherein the rodent is a mouse that expresses human or humanized DPP4 protein on the surface of T cells, wherein the amount of T cells present in the blood is between about 20% and about 200%, between about 40% and about 160%, or between about 80% and about 120% of the amount of T cells present in the blood of an age-matched mouse that expresses functional endogenous Dpp4 protein, but does not comprise said replacement.

10. The rodent of claim 1, wherein the rodent is a mouse that expresses human or humanized DPP4 protein on the surface of T cells in a level that is at least about 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130%, 140%, 150%, 160%, 170%, 180%, 190% or 200% of the level of mouse Dpp4 protein present on the surface of T cells of an age-matched mouse that expresses functional endogenous mouse Dpp4 protein, but does not comprise said replacement.

11. The rodent of claim 1, wherein the rodent is a mouse that expresses human or humanized DPP4 protein on the surface of T cells in a level that is between about 20% and about 200%, between about 40% and about 160%, or between about 80% and about 120% of the level of mouse Dpp4 protein present on the surface of T cells of an age-matched mouse that expresses functional endogenous Dpp4 protein, but does not comprise said replacement.

12. The rodent of claim 1, wherein the rodent is a mouse that expresses human or humanized DPP4 protein on the surface of cells in one or more tissues selected from the group consisting of placenta, kidney, lung, liver, skeletal muscle, heart, brain and pancreas, in a level that is at least about 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 110%, 120%, 130%, 140%, 150%, 160%, 170%, 180%, 190% or 200% of the level of mouse Dpp4 protein present on the surface of the one or more tissues of an age-

matched mouse that expresses functional endogenous mouse Dpp4 protein, but does not comprise said replacement.

13. The rodent of claim 1, wherein the rodent is a mouse that expresses human or humanized DPP4 protein on the surface of cells in one or more tissues selected from the group consisting of placenta, kidney, lung, liver, skeletal muscle, heart, brain and pancreas, at a level that is between about 20% and about 200%, between about 40% and about 160%, or between about 80% and about 120% of the level of mouse Dpp4 protein present on the surface of the one or more tissues of an age-matched mouse that expresses functional endogenous Dpp4 protein, but does not comprise said replacement.

14. The rodent of any one of claims 1-13, wherein the humanization of the endogenous rodent *Dpp4* gene is heterozygous.

15. The rodent of any one of claims 1-13, wherein the humanization of the endogenous rodent *Dpp4* gene is homozygous.

16. A method for making a humanized rodent, comprising replacing a rodent *Dpp4* gene sequence encoding rodent Dpp4 protein with a human *DPP4* gene sequence comprising one or more exons of the human *DPP4* gene sequence encoding human or humanized DPP4 protein, wherein the replacement is at an endogenous rodent *Dpp4* locus and the human *DPP4* gene sequence comprising one or more exons of the human *DPP4* gene sequence encoding human or humanized DPP4 protein is operably linked to rodent regulatory elements or sequences at the endogenous rodent *Dpp4* locus.

17. The method of claim 16, wherein the rodent is a mouse or a rat.

18. The method of claim 16, wherein the rodent regulatory elements or sequences are from a mouse or a rat.

19. The method of claim 16, wherein the rodent regulatory elements or sequences are endogenous rodent regulatory elements or sequences at the rodent *Dpp4* locus.
20. The method of claim 16, wherein the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises at least one exon of the human *DPP4* gene sequence.
21. The method of claim 20, wherein the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises at least 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 18, 20, 21, 22, 23, 24, or 25 exons of the human *DPP4* gene sequence.
22. The method of claim 21, wherein the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises all 26 exons of the human *DPP4* gene sequence.
23. The method of claim 16, wherein the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises at least one exon of the human *DPP4* gene sequence encoding the extracellular domain of the human DPP4 protein.
24. The method of claim 23, wherein the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises at least 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 18, 20, 21, 22, or 23 exons of the human *DPP4* gene sequence encoding the extracellular domain of the human DPP4 protein.
25. The method of claim 24, wherein the human *DPP4* gene sequence replacing the rodent *Dpp4* gene sequence comprises all 24 exons of the human *DPP4* gene sequence encoding the extracellular domain of the human DPP4 protein.
26. The method of claim 17, wherein the replacement is at an endogenous rodent *Dpp4* locus and the human *DPP4* gene sequence comprising one or more exons of the human *DPP4* gene sequence encoding human or humanized DPP4 protein is operably

linked endogenous rodent regulatory elements or sequences at the endogenous rodent *Dpp4* locus.

27. The method of any one of claims 16-26, wherein the rodent is heterozygous for the human *DPP4* gene sequence comprising one or more exons of the human *DPP4* gene sequence encoding the human or humanized DPP4 protein.

28. The method of any one of claims 16-26, wherein the rodent is homozygous for the human *DPP4* gene sequence comprising one or more exons of the human *DPP4* gene sequence encoding the human or humanized DPP4 protein.

29. A method for making a humanized *DPP4* mouse, comprising replacing a mouse *Dpp4* gene sequence encoding mouse Dpp4 protein with a human *DPP4* gene encoding human or humanized DPP4 protein.

30. The method of claim 29, wherein the replacement is at an endogenous mouse *Dpp4* locus, and the human *DPP4* gene encoding human or humanized DPP4 protein is operably linked to mouse regulatory sequences.

31. The method of claim 29, wherein the replacement is at an endogenous mouse *Dpp4* locus, and the human *DPP4* gene encoding human or humanized DPP4 protein is operably linked to endogenous mouse regulatory sequences.

32. The method of any one of claims 29-31, wherein the mouse is heterozygous for the human *DPP4* gene encoding the human or humanized DPP4 protein.

33. The method of any one of claims 29-31, wherein the mouse is homozygous for the human *DPP4* gene encoding the human or humanized DPP4 protein.

34. A rodent comprising a nucleic acid sequence comprising a human *DPP4* gene or fragment thereof, wherein the human *DPP4* gene or fragment thereof comprises at least

one exon of the human *DPP4* gene, and wherein the human *DPP4* gene or fragment thereof encodes a human or humanized DPP4 protein.

35. The rodent of claim 34, wherein the human *DPP4* gene or fragment thereof comprises at least 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 18, 20, 21, 22, 23, 24, or 25 exons of the human *DPP4* gene.

36. The rodent of claim 34, wherein the human *DPP4* gene or fragment thereof comprises all 26 exons of the human *DPP4* gene.

37. The rodent of claim 34, wherein the nucleic acid sequence further comprises a 5' flanking region of the human *DPP4* gene.

38. The rodent of claim 37, wherein the human *DPP4* gene or fragment thereof is operably linked to the 5' flanking region of the human *DPP4* gene.

39. The rodent of claim 38, wherein the 5' flanking region of the human *DPP4* gene comprises at least 10 kb in length.

40. The rodent of claim 39, wherein the 5' flanking region of the human *DPP4* gene comprises at least 40 kb in length.

41. The rodent of claim 38, wherein expression of the human *DPP4* gene or fragment thereof is under control of the 5' flanking region of the human *DPP4* gene.

42. The rodent of claim 34, wherein the human or humanized DPP4 protein comprises the amino acid sequence of SEQ ID NO: 24 or a fragment thereof.

43. The rodent of claim 38, wherein the rodent expresses the human or humanized DPP4 protein on the surface of T cells in a level that is at least about 20% of the level of

rodent Dpp4 protein present on the surface of T cells of an age-matched rodent that expresses functional endogenous rodent Dpp4 protein but that does not comprise the human *DPP4* gene or fragment thereof.

44. The rodent of claim 38, wherein the rodent expresses the human or humanized DPP4 protein on the surface of cells in one or more tissues selected from the group consisting of placenta, kidney, lung, liver, skeletal muscle, heart, brain, and pancreas, in a level that is at least about 20% of the level of rodent Dpp4 protein present on the surface of one or more tissues of an age-matched rodent that expresses functional endogenous rodent Dpp4 protein but that does not comprise the human *DPP4* gene or fragment thereof.

45. The rodent of claim 34, wherein the rodent expresses functional endogenous rodent Dpp4 protein.

46. The rodent of claim 34, wherein the rodent is a mouse or a rat.

47. The rodent of any one of claims 34-46, wherein the rodent is heterozygous for the human *DPP4* gene or fragment thereof.

48. The rodent of any one of claims 34-46, wherein the rodent is homozygous for the human *DPP4* gene or fragment thereof.

49. A method for making a humanized transgenic rodent, comprising integrating a nucleic acid sequence comprising one or more exons of a human *DPP4* gene sequence into a chromosome of a rodent, wherein the one or more exons of the human *DPP4* gene sequence encodes a human or humanized DPP4 protein.

50. The method of claim 49, wherein the human *DPP4* gene or fragment thereof comprises at least 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 18, 20, 21, 22, 23, 24, or 25 exons of the human *DPP4* gene.

51. The method of claim 49, wherein the human *DPP4* gene or fragment thereof comprises all 26 exons of the human *DPP4* gene.
52. The method of claim 49, wherein the nucleic acid sequence further comprises a 5' flanking region of the human *DPP4* gene.
53. The method of claim 52, wherein the human *DPP4* gene sequence is operably linked to the 5' flanking region of the human *DPP4* gene.
54. The method of claim 49, wherein the human or humanized DPP4 protein comprises the amino acid sequence of SEQ ID NO: 24 or a fragment thereof.
55. The method of claim 49, wherein the rodent is a mouse or a rat.
56. The method of any one of claims 49-55, wherein the rodent is heterozygous for the for the nucleic acid sequence comprising one or more exons of a human *DPP4* gene sequence.
57. The method of any one of claims 49-55, wherein the rodent is homozygous for the for the nucleic acid sequence comprising one or more exons of a human *DPP4* gene sequence.
58. A method for determining the *in vivo* therapeutic efficacy of a human-specific DPP4 antagonist in the rodent of any one of claims 1-15 or 34-48, the method comprising:
- (a) administering to the rodent a DPP4 antagonist, wherein the rodent is infected with Middle East respiratory syndrome coronavirus (MERS-CoV); and

(b) determining if the DPP4 antagonist treats or prevents one or more symptoms of MERS-CoV infection compared to control rodents infected with MERS-CoV who have not been administered the DPP4 antagonist.

59. The method of claim 58, wherein the DPP4 antagonist is selected from the group consisting of small molecules, peptides and antibodies.

60. The method of claim 58 or 59, wherein the DPP4 antagonist is an antibody to a MERS-CoV protein.

61. The method of claim 60, wherein the MERS-CoV protein is MERS-CoV spike protein.

62. The method of any one of claims 58-61, wherein the rodent is infected with one or more strains of MERS-CoV selected from the group consisting of Al-Hasa_1, Al-Hasa_2, Al-Hasa_3, Al-Hasa_4, Al-Hasa_12, Al-Hasa_15, Al-Hasa_16, Al-Hasa_17, Al-Hasa_18, Al-Hasa_19, Al-Hasa_21, Al-Hasa_25, Buraidah_1, EMC/2012, FRA/UAE, Hafr-Al-Batin_1, Hafr-Al-Batin_2, Hafr-Al-Batin_6, Jeddah_1, Jordan-N3/2012, Munich, Riyadh_3, Riyadh_4, Riyadh_5, Riyadh_14, Taif_1, Wadi-Ad-Dawasir_1, Riyadh_9, KFU-HKU 1, KFU-HKU 13, Qatar3, Qatar4, England 1, England-Qatar/2012, Bisha_1, Riyadh_1, and Riyadh_2.

63. The method of any one of claims 58-62, wherein the antagonist is administered before MERS-CoV infection.

64. The method of any one of claims 58-62, wherein the antagonist is administered after MERS-CoV infection.

65. The method of any one of claims 58-62, wherein the antagonist is administered simultaneously with MERS-CoV infection.

66. The method of any one of claims 58-65, wherein the symptom of MERS-CoV infection is viral titer or RNA level.
67. The method of claim 66, wherein viral titer or RNA level is assessed by one or more methods selected from the group consisting of qPCR, Northern Blot, plaque assay, and *in situ* hybridization.
68. The method of any one of claims 58-65, wherein the symptom of MERS-CoV infection is lung inflammation.
69. The method of claim 68, wherein lung inflammation is assessed histochemically.
70. The method of any one of claims 58-65, wherein the symptom of MERS-CoV infection is weight loss.