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(71) Applicant *(for all designated States except US)*: **MASSACHUSETTS EYE & EAR INFIRMARY** [US/US]; 243 Charles Street, Boston, Massachusetts 02114 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **EDGE, Albert** [US/US]; 50 Fisher Avenue, Brookline, Massachusetts 02445 (US). **FUJIOKA, Masato** [JP/US]; 1 Longfellow Place, #920, Boston, Massachusetts 02114 (US).

(74) Agent: **DEYOUNG, Janice Kugler**; Fish & Richardson P.C., P.O. Box 1022, Minneapolis, Minnesota 55440-1022 (US).

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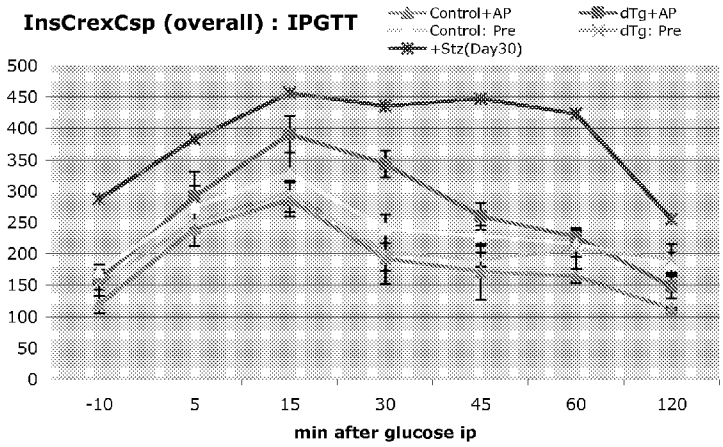
[Continued on next page]

(54) Title: CONDITIONAL-STOP DIMERIZABLE CASPASE TRANSGENIC ANIMALS

Figure 11A



(57) Abstract: Described are transgenic animals for conditional and inducible cell targeting, that express a dimerizable conditional-STOP caspase 3 transgene.

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CONDITIONAL-STOP DIMERIZABLE CASPASE TRANSGENIC ANIMALS

CLAIM OF PRIORITY

This application claims the benefit of U.S. Patent Application Serial No. 61/020,666, filed on January 11, 2008, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

This invention relates to transgenic animals, e.g., transgenic mice, with a time- and tissue-controllable death gene, constructs and cells useful in the creation of said animals, and cells derived from said animals.

BACKGROUND

A number of degenerative human diseases are characterized by the loss of specific cells in adult tissues. The availability and creation of animal models for these diseases has been hampered by the lack of a system to create models in which apoptosis can be induced in a time- and tissue-specific manner.

SUMMARY

Described herein is a transgenic mouse with an inducible caspase gene for targeted cell ablation. The transgene construct contains a bioengineered dimerizable caspase-3 gene under a stop-flox sequence, in some embodiments, the gene results in mosaic patterned, binary expression of product after recombination. Tissue specificity is determined by the choice of a Cre mouse: intersection of transgene driven by a promoter and Cre-recombinase under a promoter of choice drives engineered caspase monomer expression. The timing of cell death is controlled by administration of a dimerizer which specifically binds to a dimerizing sequence, e.g., the Fv sequence (e.g., from Ariad Inc), located upstream of caspase-3. Because caspase-3 is rapidly activated after it is dimerized, targeted cells are rapidly ablated through apoptosis after exposure to the dimerizer.

A major advantage of this mouse is the ability to achieve tissue specificity by crossing with any Cre-expressing mouse, and the inducing cell killing in the adult by administration of the chemical inducer of dimerization. The timing of Cre expression

is therefore not critical and whenever the Cre transgene is expressed the cell type marked by that gene will begin expressing caspase. Therefore, cell death can be controlled by the timing of administration of the dimerizer. This approach differs from previous approaches in which a single promoter was placed upstream of the caspase sequence because a mouse that contains the floxed STOP sequence can be used to create models for numerous cell types by crossing this new mouse with Cre mice that cover the expression of many genes. The approach also differs from the Cre-Lox approach in which a death gene is expressed as soon as a STOP sequence is removed, because in the present mice the caspase gene is inducible and is only activated after administration of the chemical inducer of dimerization to the animals that have activated the gene in the floxed cells. This allows access to a far larger pool of tissues that can be specifically ablated, including tissues that display specific Cre expression only for example during embryogenesis. This is significant when considering a tissue for targeting since many tissue specific markers are only expressed during development.

The transgenic animals described herein, e.g., mice, can be used for the targeted ablation of any cell type. These animals can be used, e.g., for the construction of models for diseases, e.g., diseases in which cells in a particular organ or tissue, or multiple organs or tissues, die. The animals can also be used as cancer models, in which a tumor formed in the animal's tissue can subsequently be destroyed by induction of caspase in that tissue. The animals can also be used to make models of cell loss and tissue degeneration, e.g., for the purpose of testing strategies for replacing the lost cells. In addition, these mice can be used experimentally to understand physiological processes and pathways, e.g., to understand the role of a specific cell type in a neural pathway, such as a sound or visual input processing pathway.

As described herein, in some embodiments not all cells of the animal express the transgene, e.g., the animals are mosaics, and are thus useful models for the onset of degenerative diseases, e.g., when the process of cell loss is ongoing, or when cell loss is only partial. In some embodiments, the double transgenic animals are mosaics as a result of incomplete recombination and mosaic expression of the transgene.

Thus, in one aspect, the invention provides transgenic non-human mammals, e.g., mice, that have a recombinant nucleic acid molecule stably integrated into their

genome. This nucleic acid molecule includes a sequence encoding a fusion protein; the fusion protein includes a cell-killing gene, e.g., a caspase, e.g., caspase 3, 8, or 9, linked in frame with a FK Binding Protein (FKBP) or variant thereof, wherein the caspase is downstream of a conditional-STOP cassette as described herein. In some embodiments, the nucleic acid molecule includes

(i) a promoter;

(ii) downstream of said promoter, a conditional-STOP cassette including a coding region of a protein, e.g., a non-toxic protein, e.g., a reporter protein, and a stop-transcription sequence, e.g., a polyadenylation signal, flanked on either side by a recombinase recognition site; and

(iii) downstream of said conditional-STOP cassette, a sequence encoding a fusion protein including a cell killing gene, e.g., a caspase, e.g., caspase 3, 8, or 9, linked in frame with a FK Binding Protein (FKBP) or variant thereof, wherein said fusion protein is not expressed when said conditional-STOP cassette is present in the construct.

In some embodiments, expression of a recombinase in a cell of said mammal results in expression of said fusion protein, and exposure of said mammal to an FKBP dimerizing agent results in death of said cells expressing recombinase.

In some embodiments, said recombinant nucleic acid molecule is operably linked to one or more regulatory sequences, e.g., a promoter.

In another aspect, the invention provides cells isolated from the non-human animals, e.g., stem cells or germ cells.

Also provided herein are methods for the production of transgenic non-human mammals, e.g., rodents, e.g., mice. The methods include introducing a recombinant nucleic acid molecule into a germ cell, an embryonic cell, or an egg cell. In some embodiments, the recombinant nucleic acid molecule includes:

(i) a promoter;

(ii) downstream of said promoter, a conditional-STOP cassette including a coding region of a protein, e.g., a non-toxic protein, e.g., a reporter protein, and polyadenylation signal, flanked on either side by a recombinase recognition site; and

(iii) downstream of said conditional-STOP cassette, a sequence encoding a fusion protein comprising a cell-killing gene, e.g., a caspase, e.g., caspase 3, 8, or 9, linked in frame with a FK Binding Protein (FKBP) or variant thereof, wherein said

fusion protein is not expressed when said conditional-STOP cassette is present in the construct.

In some embodiments, the methods further include crossing said transgenic non-human mammal with a second non-human mammal, wherein at least some of the cells of said second mammal express a recombinase that binds to and excises said stop sequence.

In another aspect, the invention provides a vector including:

(i) a promoter;

(ii) downstream of said promoter, a conditional-STOP cassette including a coding region of a non-toxic protein, e.g., a reporter protein, and polyadenylation signal, flanked on either side by a recombinase recognition site; and

(iii) downstream of said conditional-STOP cassette, a sequence encoding a fusion protein including a cell-killing gene, e.g., a caspase, e.g., caspase 3, 8, or 9, linked in frame with a FK Binding Protein (FKBP) or variant thereof, wherein said fusion protein is not expressed when said conditional-STOP cassette is present in the construct.

In some embodiments, the vector also includes one or more selection markers, e.g., negative selection markers or antibiotic resistance genes, e.g., a neomycin resistance gene, e.g., PGK-Neo. In some embodiments, the vector is a viral vector, e.g., adenoviral, retroviral, or lentiviral vector.

In some embodiments, the recombinase recognition sequence is a lox sequence, e.g., selected from the group consisting of LoxP, Lox 66, Lox 71, Lox 511, Lox 512, and Lox 514, and variants thereof. In some embodiments, the recombinase recognition sequence is a FLT sequence.

Unless otherwise defined, 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 belongs. Methods and materials are described herein for use in the present invention; other, suitable methods and materials known in the art can also be used. The materials, methods, and examples are illustrative only and not intended to be limiting. All publications, patent applications, patents, sequences, database entries, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control.

Among the advantages of the present mice over other caspase models is the fact that other models were targeted at specific cell types, i.e., they were not general models that could be crossed to any Cre mouse to create new models of degeneration. In addition, an advantage over other models that use other toxic genes, including diphtheria toxin (Ivanova et al., Genesis 43:129–135 (2005)), is that these often also target single genes; in addition, unlike the present animals that use an inducible system, those models that use a Cre-Lox strategy to allow crossing to various Cre drivers generally do not allow for temporal control of the cell death.

Other features and advantages of the invention will be apparent from the following detailed description and figures, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic illustration of a plasmid containing a conditional stop caspase-3 and a CMV promoter.

FIG. 2 is the sequence of a vector containing a floxed stop caspase-3 driven by a CMV promoter as shown in FIG. 1 (SEQ ID NO:1).

FIG. 3 is the sequence of a portion of the pC4M-Fv2E vector, which is useful in creating the fusion proteins described herein, including two FKBP sequences, one of which is the 36V FKBP (Amara et al., Proc. Natl. Acad. Sci. U.S.A. 94:10618-23 (1997)), and the other of which has several silent mutations (SEQ ID NO:2), which significantly reduce the match between the FV domains at the nucleotide level, reducing potential for recombination.

FIG. 4 is sequence alignment of FKBP1 from *Bos Taurus, Rattus norvegicus, Mus musculus, Macaca mulata, Pan troglodytes* and *Homo sapiens.* The sequence identifiers are shown in the right hand column of the figure. An asterisk in the consensus sequence (SEQ ID NO:16) indicates the presence of alternative residues, shown below the consensus sequence as alternatives 1, 2, and 3.

FIG. 5 is a schematic illustration of the one embodiment of the present invention, illustrating a plasmid and strategy for use thereof.

FIG. 6A is a bar graph showing viability by MTT assay of cells transfected with the dimerizable caspase, in the absence and presence of the dimerizing agent AP20187.

FIGs. 6B-6C are bar graphs showing cell viability (6B) and dead cells (6C) in the presence and absence of AP20187 and Cre.

FIG. 7 is a table showing the results of analysis of seven F1 animals.

FIGs. 8A-C are schematic illustrations showing the expression of lac Z (8A) or the transgene (8B-C) in cells where transgene is driven by CMV promoter in the absence (8A) or presence (8B-C) of Cre recombinase. FIG. 8B is the cell in the absence of the dimerizer; 8C shows the cell in the presence of the dimerizer.

FIGs. 9A-9F are bar graphs showing changes in auditory brain response (ABR) after dimerizer administration in Brn3c double Tg animals.

FIG. 10A is a line graph showing changes in DP-OAE after dimerizer administration in Brn3c double Tg animals.

FIG. 10B is a pair of bar graphs showing a significant increase in ISO-DP in treated Brn3c double Tg animals.

FIG. 11A is a bar graph showing effect of dimerizing agent on IGTT results in Ins-Cre double Tg animals.

FIGs. 11B-11C are bar graphs showing the effect of dimerizing agent on IGTT results in the same population of Ins-Cre double Tg animals shown in Fig. 11A, divided by sex (female, 11B; male, 11C).

FIG. 12A is a line graph showing the effect of dimerizing agent on blood sugar in Ins-Cre double Tg animals.

FIG. 12B is a bar graph showing the effect of dimerizing agent on blood sugar in Ins-Cre double Tg animals.

FIG. 13A is a gel showing the presence of Cre in the Cre mouse; lacZ in the line F transgenic mouse; both cre and lac Z, and an unrecombined 500 bp product, in the double transgenic mice, in the absence of tamoxifen (Tmx), while in the presence of tamoxifen the recombined product at 200 bp is present.

FIG. 13B is a schematic illustration of the genetic processes occurring in the double transgenic mice.

DETAILED DESCRIPTION

Described herein are transgenic animal models for timed ablation of specific cell types. The timing of ablation is controlled by dimerization of Caspase-3 using a synthetic protein, and tissue/cell specific targeting is achieved using a recombinase under the control of a cell/tissue specific promoter. For example, described are transgenic mice that have an inducible apoptosis-inducing sequence, e.g., a sequence encoding a dimerizable caspase-3 downstream of a conditional-STOP cassette, which

is a coding sequence (e.g., for a reporter such as lacZ, GFP, RFP, luciferase, or V5; a number of suitable reporters are known in the art) with a polyadenylation signal, flanked by a recombinase recognition sequence (e.g., a lox or lrt sequence), downstream of a promoter, e.g., a strong promoter such as CMV, β-actin, ROSA26, or any other ubiquitous or tissue-specific promoter. The conditional-STOP cassette prevents expression of the downstream dimerizable caspase until a cell containing the conditional-STOP caspase sequence is exposed to Cre recombinase. The caspase is regulated by a sequence encoding a dimerizable protein, e.g., an FK506 binding protein (FKBP) or variant thereof, that is cloned in frame with the sequence encoding the caspase to form a fusion protein thereof, i.e., a dimerizable caspase. The caspase is thus made as a fusion protein in which the caspase is attached to an FKBP or variant that can be dimerized by addition of a dimerizing agent, e.g., FK506 or an analog thereof, that acts as an inducer of dimerization. The whole construct, including the conditional-STOP cassette plus the dimerizable caspase sequence and the promoter, is referred to herein as a "conditional-STOP dimerizable caspase" or simply "conditional-STOP caspase."

The conditional-STOP dimerizable caspase animals described herein can be crossed with animals (of the same species) expressing a recombinase, e.g., cyclization recombination (Cre) recombinase or flippase (Flp) recombinase, e.g., expressing the recombinase in a tissue- or cell-specific manner, or alternatively engineered to express the recombinase. Thus the recombinase can be ubiquitously expressed, or expressed in a tissue- or developmental stage-restricted manner, using methods known in the art.

When the conditional-STOP dimerizable caspase animals described herein are crossed with recombinase-expressing animals, the inducible caspase gene will be expressed only in those cells in which the recombinase is expressed. The activation of cell death takes place when the caspase was activated, and the caspase is activated only when a dimerizing agent (e.g., FK506 or an analog thereof) is administered to the animal. To direct the expression of the recombinase to a specific tissue, the recombinase can be expressed under the control of a promoter that is specific to a given tissue. A number of suitable recombinase-expressing animals are known in the art, and new ones can be created using methods known in the art.

In some embodiments, an inducible recombinase can be used. For example, a Cre recombinase can be expressed as a fusion protein with a mutant form of the

mouse estrogen receptor ligand binding domain; administration of an estrogen analog (e.g., Tamoxifen) translocates the fusion protein to the nuclear compartment where it is active (see, e.g., Hayashi and McMahon, Dev Biol 244(2):305-18 (2002)). Such mice are commercially available, e.g., from Jackson Laboratory, Bar Harbor, Maine (e.g., the JAX® GEMM® Strain).

As one example, the conditional-STOP caspase mouse can be crossed with an Ins-Cre mouse (see, e.g., Ray et al., Int. J. Pancreatol. 25(3):157-63 (1999)), which expresses Cre under the control of the insulin promoter. In the offspring, the conditional-STOP caspase sequence will be expressed in the beta cells of the pancreas, where the insulin promoter drives the expression of Cre. Administration of the dimerizing agent (e.g., FK506 or an analog thereof) activates the dimerizable caspase in the beta cells of the pancreas. The dimerized caspase kills the cells, and the mouse then develops diabetes. In this way the timing of the inducible death can be determined, and both the time and location of cell death can be controlled.

Cre mice, e.g., mice that express Cre at a discrete time period during development (such as GATA3-Cre), can be crossed with the conditional-STOP caspase mice described herein, since the STOP sequence would be removed and the caspase gene would be expressed. Such a mouse could be treated with an FK analogue at any time in its life and the caspase would be activated in any tissues that had expressed the gene in question at an earlier time point; once recombination has occurred, the caspase monomer would be expected to be expressed in the cell for the rest of the cell's lifetime. In a model that used Cre recombinase to induce apoptosis immediately, cell types that express Cre in the embryo would be killed and the mice would likely not be viable models. Since many tissue specific genes are known from embryonic development, and numerous Cre mice that express these genes are available, this is a significant avenue for development of disease models and models for the study of pathways by cell ablation.

In general, the transgenic animals described herein can be made by constructing a vector in which a conditional-STOP cassette is placed in the sequence upstream of a dimerizable caspase; the order in which the construct is made is unimportant, so that, for example, the dimerizing sequence can equally be added to a caspase-encoding sequence that already contains a conditional-STOP cassette. The conditional-STOP cassette and dimerizable caspase are placed under the control of a

promoter, e.g., a strong ubiquitous or tissue-specific promoter. The resulting vectors are injected into the pronucleus of a fertilized oocyte and used for generation of a transgenic animal with the conditional-STOP dimerizable caspase expressed in all cells in which the promoter is active. This animal can be crossed with a transgenic recombinase-expressing animal to create a new animal in which the caspase is expressed only where and when the recombinase is expressed. For example, crossing with an animal that expresses a recombinase under the control of a promoter from a cell-type specific gene will allow the targeted deletion of a cell type that is characterized by expression of the gene that is normally driven by the promoter that was used for Cre expression.

In at least some of the animals generated using the methods described herein, transgene expression may not be uniform throughout the animals. As described in Example 3, below, variable transgene expression was seen in three lines of animals. This variability of transgene expression among different lines can be used as a "second gate-keeper" for tissue/cell-type specific expression. Therefore, the methods can include selecting a mouse line expressing the dimerizable caspase in the desired cells or tissues. Final expression pattern of FKBP-Caspase monomer is defined by the intersection of Cre recombinase and the CMV promoter-derived dimerizable caspase transgene.

Transgenic Animals and Methods of Use

In one aspect, the invention provides non-human transgenic animals having conditional-STOP dimerizable caspase transgene constructs integrated into their genome. In some embodiments, the transgenes make use of the Cre-lox system or the Flp-FRT system.

A "transgenic animal" is a non-human animal, such as a mammal, generally a rodent such as a rat or mouse, in which one or more of the cells of the animal includes a transgene as described herein. Other examples of transgenic animals include non-human primates, sheep, dogs, cows, goats, chickens, amphibians, and the like. A "transgene" is exogenous DNA that is integrated into the genome of a cell from which a transgenic animal develops and thus remains in the genome of the mature animal, thereby directing the expression of an encoded gene product in one or more cell types or tissues of the transgenic animal. Knock-in animals, which include a gene insertion, are included in the definition of transgenic animals.

A "conditional-STOP cassette" as used herein refers to a construct that features recombinase recognition sequences flanking a coding and polyadenylation signal, e.g., a coding sequence for a protein, preferably a non-toxic protein, e.g., a reporter protein, inserted downstream of a promoter and upstream of the coding sequence of a dimerizable caspase fusion protein, so as to prevent expression of the dimerizable caspase in the absence of a recombinase. The promoter instead drives expression of the reporter protein, and transcription is stopped by the polyadenylation signal. Excision of the conditional-STOP cassette removes the polyadenylation and coding region, and allows the caspase to be expressed from the upstream promoter. The transgene is generally integrated into or occurs in the genome of the cells of a transgenic animal. A "recombinase recognition sequence" as used herein refers to a sequence that directs the recombinase-mediated excision or rearrangement of DNA. Such sequences include lox and FRT sequences, as known in the art and described herein (the term "floxed," as used herein, refers to a pair of lox sequences that flank a region to be excised, in this case, a stop sequence. Although "flox" generally refers to a flanking pair of LoxP sequences, in the present application the term "flox" or "floxed" is used to refer to any flanking pair of recombinase recognition sequences including any lox or FRT sequences.

The conditional-STOP cassette can be used to express the dimerizable caspase fusion protein in one or more cell types or tissues of the transgenic animal in the presence of the Cre or Flp recombinase; expression of the recombinase in a cell harboring the conditional stop transgene results in excision of the sequence encoding the non-toxic protein, e.g., the reporter protein, and its polyadenylation signal, and expression of the dimerizable caspase fusion protein. Thus, a transgenic animal as described herein is one in which at least one copy of a conditional-STOP dimerizable caspase fusion protein has been introduced into a cell of the animal, e.g., an embryonic cell of the animal, prior to development of the animal. A line of transgenic animals (e.g., mice, rats, guinea pigs, hamsters, rabbits, or other mammals) can be produced bearing a transgene encoding a conditional-STOP dimerizable caspase fusion protein in some or all of their cells. Methods known in the art for generating such transgenic animals would be used, e.g., as described below.

The use of the Cre-lox system to direct site-specific recombination in cells and transgenic animals is described in Orban et al., Proc. Natl. Acad. Sci. USA

89(15):6861-5 (1992); Akagi et al., Nuc. Acids Res. 25(9):1766-1772 (1997); Lakso et al., Proc. Natl. Acad. Sci. USA 89:6232-6236 (1992); Rossant and McMahon, Genes Dev. 13(2)142-145 (1999); Wang et al., Proc. Natl. Acad. Sci. USA 93:3932-3936 (1996). The use of the Flp-FRT system to direct site-specific recombination in transgenic animals is described in U.S.S.N. 08/866,279, Publication No. U.S. 2002/0170076; Vooijs et al., Oncogene. 17(1):1-12 (1998); Ludwig et al., Transgenic Res. 5(6):385-95 (1996); and Dymecki et al., Dev. Biol. 201(1):57-65 (1998). Methods known in the art for producing transgenic animals can be used to generate an animal, e.g., a mouse, that bears one conditional dimerizable caspase fusion protein "allele." Two such heterozygous animals can be crossed to produce offspring that are homozygous for the conditional dimerizable caspase fusion protein allele, i.e., have the sequence encoding the dimerizable caspase fusion protein integrated into both copies of a chromosome.

For example, in one embodiment, a suitable vector including a sequence encoding the conditional-STOP dimerizable caspase is introduced into a cell, e.g., a fertilized oocyte or an embryonic stem cell. Such cells can then be used to create non-human transgenic animals in which said sequences have been introduced into their genome. These animals can then in turn be bred with other transgenic animals that express a recombinase, e.g., under the control of a cell-, tissue-, or timing-specific promoter, e.g., a promoter that will turn on expression of the caspase in a specific cell or tissue, or at a specific time in development. Expression of a recombinase in the cell or tissue will result in excision of the stop sequence and allow the conditional dimerizable caspase fusion protein to be expressed. Administration of a dimerizing agent, e.g., FK506 or an analog thereof, to the animal will then cause dimerization of the caspase fusion protein, activating it and initiating apoptosis in the cells. Such animals are useful for studying the effects of cell death in specific tissues, in both young and adult mammals.

Methods for generating transgenic animals, particularly animals such as mice, via embryo manipulation and electroporation or microinjection of pluripotent stem cells or oocytes, are known in the art and are described, for example, in U.S. Patent Nos. 4,736,866 and 4,870,009, U.S. Patent No. 4,873,191, U.S.S.N. 10/006,611, "Transgenic Mouse Methods and Protocols (Methods in Molecular Biology)," Hofker and van Deursen, Editors (Humana Press, Totowa, N.J., 2002); and in "Manipulating

the Mouse Embryo," Nagy et al., Editors (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 2002), which are incorporated herein by reference in their entirety. Methods similar to those used to create transgenic mice can be used for production of other transgenic animals.

In general, in the present methods, a transgenic mouse as described herein is made by injecting a vector made as described herein into the pronucleus of a fertilized mouse oocyte and used for generation of a transgenic mouse with the inducible caspase expressed in all cells, using standard transgenic techniques, e.g., as described in "Transgenic Mouse Methods and Protocols (Methods in Molecular Biology)," Hofker and van Deursen, Editors (Humana Press, Totowa, N.J., 2002); U.S. Patent Nos. 4,736,866 and 4,870,009, U.S. Patent Nos. 4,873,191 and 6,791,006, and in Hogan, "Manipulating the Mouse Embryo," Nagy et al., Editors (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 2002).

A transgenic founder animal can be identified based upon the presence of the conditional dimerizable caspase fusion protein transgene in its genome, for example by detecting the presence of the recombinase recognition sequences (e.g., lox or FRT), or by detecting the presence of the FKBP. Founder animals can also be identified by detecting the presence or expression of the conditional-STOP dimerizable caspase fusion protein mRNA in tissues or cells of the animals in the presence and/or absence of recombinase, e.g., Cre or Flp. For example, fibroblasts can be used, such as embryonic fibroblasts or fibroblasts derived from the post-natal animal, e.g., the ear of the post-natal animal. A transgenic founder animal can then be used to breed additional animals carrying the transgene. Moreover, transgenic animals carrying a conditional-STOP dimerizable caspase fusion protein transgene can further be bred to other transgenic animals carrying other transgenes. For example, as noted above, such conditional-STOP dimerizable caspase transgenic animals can be bred to animals expressing a suitable recombinase, e.g., a recombinase under the control of a selected promoter, e.g., a cell-, tissue-, or timing-specific promoter, to induce the apoptosis of specific cells or tissues, e.g., at a specific time.

Once a mouse is obtained that contains the dimerizable conditional-STOP caspase fusion protein transgene in some or all of its somatic and germ cells, this mouse can be crossed with a mouse expressing a suitable recombinase to create a new mouse in which the caspase is expressed, e.g., in a cell type of choice. This will then

allow the targeted and conditional deletion of a cell type that is characterized by expression of the gene that would be driven by the promoter that was used for Cre expression, in the presence of a dimerizing agent, e.g., FK506 or an analog thereof.

Vectors

In another aspect, the invention includes, vectors, preferably expression vectors, containing a nucleic acid encoding a dimerizable conditional-STOP caspase fusion protein as described herein. As used herein, the term "vector" refers to a nucleic acid molecule capable of transporting another nucleic acid to which it has been linked and can include a plasmid, cosmid or viral vector. The vector can be capable of autonomous replication or it can integrate into a host DNA. Viral vectors include, e.g., replication defective retroviruses, adenoviruses and adeno-associated viruses.

A vector can include a nucleic acid encoding a dimerizable conditional-STOP caspase fusion protein in a form suitable for expression of the nucleic acid in a host cell. Preferably the recombinant expression vector includes one or more regulatory sequences operatively linked to the nucleic acid sequence to be expressed. The term "regulatory sequence" includes promoters, enhancers and other expression control elements (e.g., polyadenylation signals). Regulatory sequences include those which direct constitutive expression of a nucleotide sequence, as well as tissue-specific regulatory and/or inducible sequences. The design of the expression vector can depend on such factors as the choice of the host cell to be transformed, the level of expression of protein desired, and the like. The expression vectors of the invention can be introduced into host cells to thereby produce the dimerizable conditional-STOP caspase fusion protein, encoded by nucleic acids as described herein.

The recombinant expression vectors described herein can be designed for expression of dimerizable conditional-STOP caspase fusion proteins in prokaryotic or eukaryotic cells. For example, polypeptides of the invention can be expressed in *E. coli*, insect cells (e.g., using baculovirus expression vectors), yeast cells or mammalian cells. Suitable host cells are discussed further in Goeddel, "Gene Expression Technology: Methods in Enzymology 185," Academic Press, San Diego, CA (1990). Alternatively, the recombinant expression vector can be transcribed and translated in vitro, for example using T7 promoter regulatory sequences and T7 polymerase. When used in mammalian cells, the expression vector's control

functions are often provided by viral regulatory elements. For example, commonly used promoters are derived from polyoma, Adenovirus 2, cytomegalovirus and Simian Virus 40.

In some embodiments, the invention includes recombinant mammalian expression vectors that are capable of directing expression of the nucleic acid encoding a dimerizable conditional-STOP caspase fusion protein preferentially in a particular cell type (e.g., tissue-specific regulatory elements are used to express the nucleic acid). Non-limiting examples of suitable tissue-specific promoters include the albumin promoter (liver-specific; Pinkert *et al.* (1987) Genes Dev. 1:268-277), lymphoid-specific promoters (Calame and Eaton (1988) Adv. Immunol. 43:235-275), in particular promoters of T cell receptors (Winoto and Baltimore (1989) EMBO J. 8:729-733) and immunoglobulins (Banerji et al. (1983) Cell 33:729-740; Queen and Baltimore (1983) Cell 33:741-748), neuron-specific promoters (e.g., the neurofilament promoter; Byrne and Ruddle (1989) Proc. Natl. Acad. Sci. USA 86:5473-5477), pancreas-specific promoters (Edlund et al. (1985) Science 230:912-916), and mammary gland-specific promoters (e.g., milk whey promoter; U.S. Patent No. 4,873,316 and European Application Publication No. 264,166). Developmentally-regulated promoters are also encompassed, for example, the murine hox promoters (Kessel and Gruss (1990) Science 249:374-379) and the α-fetoprotein promoter (Campes and Tilghman (1989) Genes Dev. 3:537-546).

Cells

In another aspect, the invention provides isolated cells that include a nucleic acid molecule as described herein, e.g., a nucleic acid molecule encoding a dimerizable conditional-STOP caspase fusion protein within a recombinant expression vector, or a nucleic acid molecule containing sequences that allow it to homologously recombine into a specific site of the host cell's genome. The terms "host cell" and "recombinant host cell" are used interchangeably herein. Such terms refer not only to the particular subject cell that was contacted with a nucleic acid molecule (e.g., a vector as described herein), but to the progeny or potential progeny of such a cell that also contain the nucleic acid molecule. Because certain modifications may occur in succeeding generations due to either mutation or environmental influences, such progeny may not, in fact, be identical to the parent cell, but are still included within

the scope of the term as used herein so long as they also contain the nucleic acid molecule.

A host cell can be any prokaryotic or eukaryotic cell. For example, the cell can be a bacterial cell such as *E. coli*, insect cells, yeast or mammalian cells (such as Chinese hamster ovary cells (CHO), HEK, or COS cells). Other suitable host cells are known to those skilled in the art. Where the vector is a viral vector that can be produced from recombinant cells, e.g., retroviral vectors, the cells can be those that produce the viral vector.

Vector DNA can be introduced into host cells via conventional transformation or transfection techniques. As used herein, the terms "transformation" and "transfection" are intended to refer to a variety of art-recognized techniques for introducing foreign nucleic acid (e.g., DNA) into a host cell, including calcium phosphate or calcium chloride co-precipitation, DEAE-dextran-mediated transfection, lipofection, or electroporation. In some embodiments, naked DNA is simply applied to a cell. Where the vector is a viral vector, known infection protocols can be used.

For example, retroviral vectors can be used, e.g., as described in Robertson et al., Nature 323:445-448 (1986). Retroviruses generally integrate into the host genome with no rearrangements of flanking sequences, which is not always the case when DNA is introduced by microinjection or other methods.

Cells of the present invention also include those cells obtained from the transgenic animals described herein, e.g., cells from the tissues of those animals, that contain the nucleic acid molecule.

Identity of Sequences

To determine the percent identity of two amino acid sequences, or of two nucleic acid sequences, the sequences are aligned for optimal comparison purposes (e.g., gaps can be introduced in one or both of a first and a second amino acid or nucleic acid sequence for optimal alignment and non-homologous sequences can be disregarded for comparison purposes). The length of a reference sequence (e.g., an FKBP sequence shown in Figure 4) aligned for comparison purposes is at least 80% of the length of the reference sequence, and in some embodiments is at least 90%, 95% or 100%. The amino acid residues or nucleotides at corresponding amino acid positions or nucleotide positions are then compared. When a position in the first sequence is occupied by the same amino acid residue or nucleotide as the

corresponding position in the second sequence, then the molecules are identical at that position. The percent identity between the two sequences is a function of the number of identical positions shared by the sequences, taking into account the number of gaps, and the length of each gap, which need to be introduced for optimal alignment of the two sequences.

The comparison of sequences and determination of percent identity between two sequences can be accomplished using a mathematical algorithm. For the present methods, the percent identity between two amino acid sequences is determined using the Needleman and Wunsch ((1970) J. Mol. Biol. 48:444-453) algorithm, which has been incorporated into the GAP program in the GCG software package (available on the world wide web at gcg.com), using the default parameters, i.e., a Blossum 62 scoring matrix with a gap penalty of 12, a gap extend penalty of 4, and a frameshift gap penalty of 5.

Caspases

The cysteine-aspartic acid proteases (caspase) are a family of related proteins, sequential activation of which plays a central role in the execution phase of apoptosis. Caspases exist as inactive proenzymes which undergo proteolytic processing at conserved aspartic residues to produce two subunits, large and small, that dimerize to form the active enzyme. Caspase 3 cleaves and activates caspases 6, 7 and 9, and the protein itself is processed by caspases 8, 9 and 10.

Caspase 3

Alternative splicing of the Caspase 3 gene results in two transcript variants that encode the same protein. The sequence of the longer human caspase 3 preproprotein variant can be found at GenBank Acc. Nos. NM_004346.3 (nucleic acid) and NP_004337.2 (amino acid); the sequence of the shorter variant (beta), which differs in the 5' UTR, is at NM_032991.2 (nucleic acid) and NP_116786.1 (amino acid).

Caspase 8

Caspase 8 is involved in the programmed cell death induced by Fas and various apoptotic stimuli. A number of isoforms exist as a result of alternative splicing, including:

Nucleic acid	Amino acid	Name	Description
NM_001228.4	NP_001219.2	caspase 8	Variant (A), also known as Alpha-

		isoform A precursor	4, has multiple differences in the 5' UTR and coding region, compared to variant G. It encodes isoform A which is shorter than isoform G.
NM_033355.3	NP_203519.1	caspase 8 isoform B precursor	Variant (B) includes different segments in its 5' UTR and lacks a 5' coding region segment, compared to variant G. This results in translation at a downstream start codon, and the encoded protein (isoform B) has a shorter N-terminus when it is compared to isoform G.
NM_033356.3	NP_203520.1	caspase 8 isoform C precursor	Variant (C) includes a different segment in the 5' UTR and lacks an alternate in-frame segment in the coding region, compared to variant G. Variants C and F both encode isoform C, which is shorter than isoform G. Isoform C has also been labelled as Alpha-2 or MCH5-beta.
NM_033358.3	NP_203522.1	caspase 8 isoform E	Variant (E), also known as Beta-1, has multiple differences, one of which causes a frameshift, compared to variant G. It encodes isoform E, which is shorter than isoform G.
NM_001080124.1	NP_001073593.1	caspase 8 isoform C precursor	Variant (F) includes different segments in the 5' UTR and lacks an alternate in-frame segment in the coding region, compared to variant G, but variants C and F both encode isoform C, which is shorter than isoform G.
NM_001080125.1	NP_001073594.1	caspase 8 isoform G precursor	Variant (G), also known as procaspase-8L or 8L, encodes the longest protein (isoform G).

Caspase 9

Caspase 9 also has multiple isoforms resulting from alternative splicing. The alpha transcript variant (NM_001229.2, caspase 9 isoform alpha preproprotein) represents the longer transcript and encodes the longer isoform (alpha, NP_001220.2). The beta variant (NM_032996.1 caspase 9 isoform beta preproprotein) lacks several exons in the coding region but maintains the reading frame, compared to variant

alpha. It encodes isoform beta (NP_127463.1) which is shorter than isoform alpha. Isoform beta lacks protease activity and acts as an apoptosis inhibitor, and is therefore not suitable for use in methods intended to produce an apoptotic response.

Thymidine Kinase

TK can also be used, e.g., thymidine kinase 1, soluble, the sequence for which is NM_003258.3 (nucleic acid), which encodes NP_003249.2 (amino acid)

FK Binding Proteins and Variants

FK506 binding proteins (FKBPs) are abundant and relatively ubiquitous cytosolic proteins, members of the peptidyl-prolyl *cis-trans* isomerases (PPIases), which catalyze *cis-trans* conversions about Xaa-Pro bonds. FKBPs are a receptor for immunosuppressant macrolides rapamycin, FK506, and FK1706. FKBPs range in size from 12 kDa to 135 kDa. For the purposes of the present methods, the 12kDa FKBPs, referred to as FKBP1 and/or FKBP12, are preferred; in particular, the variant of FKBP12 engineered to bind AP20187 is preferred (see, e.g., Clackson et al., Proc. Natl. Acad. Sci. USA 95: 10437–10442 (1998); vectors and sequences commercially available from Ariad Pharmaceuticals, Inc., Cambridge, MA). FKBP1 has also been referred to as protein kinase C inhibitor-2 (PKCI2).

In mammalian systems, there are two isoforms of FKBP1. The sequences are available in GenBank under Acc. Nos. NM_054014.1 (nucleic acid) and NP_463460.1 (amino acid) for a shorter mRNA form; and NM_000801.2 (nucleic acid) and NP_000792.1 (amino acid) for a longer mRNA form. A sequence alignment of FKBP1 from *Bos Taurus, Rattus norvegicus, Mus musculus, Macaca mulata, Pan troglodytes* and *Homo sapiens* appears in Figure 4.

Other FKBPs are known in the art, e.g., FKBP12.6, and FKBP51. See, e.g., Weiwad et al., Biochemistry, 45(51):15776-15784 (2006).

The transgene constructs described herein comprise a sequence encoding an FKBP or a variant thereof. In some embodiments, the FKBP is a wild-type FKBP, e.g., a mammalian sequence as shown in Figure 4. In some embodiments, the constructs described herein are made using a sequence that is at least 80% identical to a sequence that appears in Figure 4, e.g., at least 90%, 92%. 94%, 95%, 97%, 98%, or 99% identical. In some embodiments the sequence used differs by at least one but by less than 30, 25, 20, 15, 10 or 5 amino acid residues. In some embodiments, it differs

from the corresponding sequence in Figure 4 by at least one residue, but less than 20%, 15%, 10% or 5% of the residues in it differ from the corresponding sequence in Figure 4.

In general, any and all substitutions will be conservative substitutions. A "conservative amino acid substitution" is one in which the amino acid residue is replaced with an amino acid residue having a similar side chain. Families of amino acid residues having similar side chains have been defined in the art. These families include amino acids with basic side chains (e.g., lysine, arginine, and histidine), acidic side chains (e.g., aspartic acid, and glutamic acid), uncharged polar side chains (e.g., glycine, asparagine, glutamine, serine, threonine, tyrosine, and cysteine), nonpolar side chains (e.g., alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, and tryptophan), beta-branched side chains (e.g., threonine, valine, and isoleucine) and aromatic side chains (e.g., tyrosine, phenylalanine, tryptophan, and histidine).

All variants useful in the methods described herein will retain the ability to bind a dimerizing agent as described herein, e.g., FK506, and the ability to dimerize in response to binding of such an agent.

A consensus sequence appears at the bottom of Figure 4. Those amino acids which are important in function of FKBP are known in the art, see, e.g., Somarelli and Herrera, Biol. Cell. 99(6):311-21 (2007). Figure 4 also provides the sequences of additional FKBP1s from various other species.

Methods for constructing transgenes useful in the present methods are known in the art; see, e.g., Sambrook and Russell, "Molecular Cloning: A Laboratory Manual," Cold Spring Harbor Laboratory Press; 3rd Labman edition (January 15, 2001); and Ausubel et al., Eds., "Short Protocols in Molecular Biology," Current Protocols; 5 edition (November 5, 2002). In some embodiments, commercially-available vectors can be used in constructing the nucleic acid molecules described herein, e.g., pC4M-Fv2E (available from Ariad Pharmaceuticals, Cambridge, MA). In some embodiments, more than one FKBP will be fused in frame with the caspase. For example, two, three, or more FKBP can be used. The vector pC4M-Fv2E (available from Ariad Pharmaceuticals, Cambridge, MA), a partial sequence of which is shown in Figure 3, can be used to produce a fusion protein with two FKBPs fused in frame with the caspase.

FKBP Dimerizing Agents

The methods described herein include the use of FKBP dimerizing agents to induce dimerization, and thus activation, of the dimerizable conditional-STOP caspase fusion proteins described herein.

A number of suitable FKBP dimerizing agents are known in the art. These agents include FK506, rapamycin, and analogs of rapamycin or FK506.

Analogs of FK506 include, e.g., substituted 5,5-dimethyl-2-(4-thiazolidine)carboxylates, polycyclic aza-amide analogs, aza-proline and aza-pipecolic acid analogs. Specific analogs include L-685818, (R)- and (S)-[18-OH]ascomycin, 3-(3-pyridyl)-1-propyl (2S)-5,5-dimethyl-1-(3,3-dimethyl-1,2-dioxobutyl)-2-(4-thiazolidine)carboxylate), FK1706, FK1012, GPI-1046 and non-cyclic derivatives of GPI-1046, A-119435, and AP1510. See, e.g., Petros et al., FEBS Lett. 308(3):309-314 (1992); Hudak et al., J Med Chem. 49(3):1202-6 (2006); Zhao et al., J Med Chem. 49(14):4059-71 (2006); Zhao et al., Bioorg Med Chem Lett. 16(16):4385-90 (2006); Fujitani et al., J Chem Phys. 123(8):084108 (2005); Mollison et al., J. Pharm. Exp. Ther. 283(3):1509-1519 (1997); and Wilkinson et al., Bioorg. Med. Chem. 11:4815-4825 (2003). For FK506 and analogous fermentation products, see also, e.g., U.S. Pat. No. 4,894,366 and the more recent WO 04/78167.

Analogs of rapamycin include C-43-modified rapamycin analogs, e.g., AP23573 (see WO 03/064383), temsirolimus (CC1779, see WO 2004/026280), everolimus (U.S. Pat. No. 6,384,046 and references cited therein), and ABT-578 (a rapamycin derivative bearing a tetrazole moiety in place of the OH at position 43, see US PGPub No. 20060194829); see also US PGPub Nos. 20060194829, 20060078980, and 20050272132. Additional rapamycin analogs are known in the art, see, e.g., WO 01/144387; WO 97/10502; WO 94/18207; WO 93/04680; U.S. Pat. No. 5527907; U.S. Pat. No. 5225403; WO 96/41807; WO 94/10843; WO 92/14737; U.S. Pat. No. 5484799; U.S. Pat. No. 5221625; WO 96/35423; WO 94/09010; WO 92/05179; U.S. Pat. No. 5457194; U.S. Pat. No. 5210030 WO 96/03430 WO 94/04540; U.S. Pat. No. 5604234; U.S. Pat. No. 5457182; U.S. Pat. No. 5208241; WO 96/00282; WO 94/02485; U.S. Pat. No. 5597715; U.S. Pat. No. 5362735; U.S. Pat. No. 5200411; WO 95/16691; WO 94/02137; U.S. Pat. No. 5583139; U.S. Pat. No. 5324644; U.S. Pat. No. 5198421; WO 95/15328; WO 94/02136; U.S. Pat. No. 5563172; U.S. Pat. No. 5318895; U.S. Pat. No. 5147877; WO 95/07468; WO 93/25533; U.S. Pat. No.

5561228; U.S. Pat. No. 5310903; U.S. Pat. No. 5140018; WO 95/04738; WO 93/18043; U.S. Pat. No. 5561137; U.S. Pat. No. 5310901; U.S. Pat. No. 5116756; WO 95/04060; WO 93/13663; U.S. Pat. No. 5541193; U.S. Pat. No. 5258389; U.S. Pat. No. 5109112; WO 94/25022; WO 93/11130; U.S. Pat. No. 5541189; U.S. Pat. No. 5252732; U.S. Pat. No. 5093338; WO 94/21644; WO 93/10122; U.S. Pat. No. 5534632; U.S. Pat. No. 5247076; and U.S. Pat. No. 5091389.

In addition, a new generation of FKBP dimerizing agents has been developed that do not bind to the native FKBPs, but bind with high affinity to FKBPs with a single amino acid substitution: Phe36Val; see SEQ ID NO:15. These new agents include AP1889, AP1903 and AP20187. Additional information regarding these reagents can be found in the art, including in the following references: Spencer et al., Science 262:1019-24 (1993); Amara et al., Proc Natl Acad Sci U S A 94:10618-23 (1997); Clackson et al., Proc Natl Acad Sci U S A 95:10437-42 (1998); and Pollock and Rivera, Methods Enzymol 306: 263-81 (1999).

Finally, numerous additional agents are listed in U.S. Pat. Pub. No. 2006/0194829, 2006/0078980, and 20050272132.

In a preferred embodiment, the dimerizing agent is AP20187, available from Ariad. In mice, a 0.5-10 mg/kg dose of AP20187 delivered i.p. will generally give a good response, but a range of concentrations (e.g., from 0.005 to 10 mg/kg) is also recommended to find the lowest effective dose.

Conditional-STOP Cassettes

In the conditional-STOP dimerizable caspase constructs described herein, a conditional-stop cassette is included that prevents expression of the downstream caspase. The cassette includes a first recombinase recognition site, a cDNA encoding a protein, at least one polyadenylation signal to stop transcription, and a second recombinase recognition site. In some embodiments, the protein is a non-toxic protein, e.g., a reporter protein, e.g., lacZ (which encodes beta-galactosidase); luciferase; a fluorescent protein, such as green fluorescent protein (GFP), red FP (RFP), yellow FP (YFP), or a variant thereof; or V5. A "non-toxic" protein is a protein that, when expressed in a cell, is not generally associated with significant cell death. Preferably the protein will not have a significant effect on cell function or physiology. Expression of the protein is driven by the promoter included in the construct, and the presence of the polyadenylation signal prevents transcription of the

downstream caspase until a recombinase excises the cassette including the protein and polyadenylation signal, after which the caspase is expressed. See, e.g., Moeller et al., Am. J. Physiol. Renal. Physiol. 289(2):F481-8 (2005). The protein and the dimerizable caspase are not the same protein.

Recombinase-Expressing Transgenic Mice

Once a mouse is obtained that contains the transgene in all of its somatic and germ cells, this mouse can be crossed with any mouse with cell or tissue-specific expression of a recombinase, e.g., Cre or Flp, to create a new mouse in which the caspase is expressed in a cell type of choice. This will then allow the targeted and conditional deletion of a cell type that is characterized by expression of the gene that would be driven by the promoter that was used for Cre expression, in the presence of the dimerizing agent, e.g., FK506.

Hundreds of recombinase-expressing mice have been described and are commercially available; for example, Jackson Laboratory of Bar Harbor, Maine, lists over 200 such mice on their website. A few examples include the strain B6.Cg-Tg(Camk2a-cre)T29-1Stl/J. These transgenic mice express the Cre recombinase under the control of the mouse calcium/calmodulin-dependent protein kinase II alpha promoter. Cre recombinase is expressed only in the forebrain, specifically in the CA1 pyramidal cell layer in the hippocampus. When crossed with a strain containing loxP site flanked sequence of interest, Cre-mediated recombination occurs in the pyramidal cell layer. Another strain, FVB-Tg(Ckmm-cre)5Khn/J, have a cre recombinase gene driven by the muscle creatine kinase (MCK or Ckm) promoter. Cre activity is observed in skeletal and cardiac muscle. Inner hair cell Cre-expressing transgenic mice are described in Li et al., Genesis 39(3):173-7 (2004) and Tian et al., Dev Dyn. 231(1):199-203 (2004); Pirvola et al., Neuron 35(4):671-80 (2002), and Chow et al., Dev Dyn. 235(11):2991-8 (2006).

Other inner ear-specific genes include Ngn1 (neurogenin 1), islet1, Gata3 (neurons), Math1 (hair cells), and Prox1, Sox2, and musashi (supporting cells).

In some embodiments, the methods described herein can be used with mice that express a recombinase in one or more selected cell types or organs, e.g., selectively in one or more cell types of the brain, ear, skin, connective tissue, muscle, bone, and/or internal organ(s), e.g., heart, lungs, liver, kidneys, or pancreas.

Double transgenic mice obtained by breeding F_1 transgenic mice generated as described herein Example 3 can be crossed using standard breeding methods with selected Cre-expressing mice, e.g.,

-Insulin-Cre: Diabetes model (targeting islet cells)

-keratin15-Cre: Baldness model (targeting hair follicle stem cells)

-pou4f3-Cre (also know as Brn3c): Hearing loss model (targeting cochlear sensory cell)

-ngn1-CreER (neurogenin): Hearing loss model (targeting ganglion neurons) (Jackson Labs)

-TTR-Cre (transthyretin): (targeting hepatocytes)(see, e.g., Mallet et al., Nat. Biotech. 20:1234-1239 (2002)

-Rosa26-CreER: ubiquitous, for *in vitro* experiments

For example, crossing the STOP-flox-caspase3 mice to a Kr15-Cre mouse will make the hair cell follicles susceptible to FK506 analogue induced cell death. A number of Cre-expressing mice are available commercially, e.g., from Jackson Labs, Bar Harbor, Maine.

Most degenerative diseases begin with gradual and incomplete loss of specific cell types, yet the models for "onset" of these diseases have not fully been established. Moderate but low-variation cell ablation is technically difficult when the model is created either by drug treatment or gene manipulation. The present mouse model successfully recapitulates the partial loss of cells typically seen in degenerative diseases: mosaic-patterned stochastic cell ablations within specific cell types.

In some embodiments, the methods described herein can be used to create mice that are models of genetic diseases with single or multiple gene defects that lead to loss of one or several cell types, e.g., Huntington's disease or Parkinson's disease (e.g., using one or more Cre recombinases that target dopaminergic cells, e.g., in the substantia nigra, e.g., as described in Lemberger et al., BMC Neuroscience, 8:4 (2007), or under the control of a tyrosine hydroxylase gene 3' UTR, e.g., as described in Lindepberg et al., Genesis, 40(2):67 – 73 (2004)), and muscular dystrophy (e.g., using a dystrophin-promoter driven Cre). In some embodiments, the disease is a later-onset disease, e.g., adult-onset. Additional exemplary mouse models and diseases include: Insulin-Cre: Diabetes model (targeting islet cells); keratin15-Cre: Baldness model (targeting hair follicle stem cell); pou4f3-Cre: Hearing loss model (targeting

cochlear sensory cells); ngn1-CreER: Hearing loss model (targeting ganglion neurons); and Rosa26-CreER: useful for in vitro experiment.

EXAMPLES

The invention is further described in the following examples, which do not limit the scope of the invention described in the claims.

Example 1: Construction of a Conditional-Stop Caspase Vector

This Example describes methods for constructing a vector in which a conditional-STOP cassette is placed upstream of an inducible caspase. The cDNA for the floxed STOP caspase3 was generated by engineering the caspase gene with a FK506 analogue binding site and a myristoylation sequence into a plasmid containing a STOP-flox sequence in conjunction with a LacZ gene (Moeller et al., Am. J. Physiol. Renal Physiol. 289(2):F481-8 (2005)).

A transgene that irreversibly expressed AP20187 (an FK506-analogue)-responsive human myristoylated procaspase-3 under the control of a CMV-promoter after co-expression of Cre-recombinase was constructed as follows.

The 1583 bp coding sequence of M-Fv2-Casp3-E was subcloned from pSH1/M-Fv2-Casp3-E (Mallet et al., Nat. Biotech. 20:1234-1239 (2002)) into the pDrive-9 transit plasmid using the QIAGEN PCR cloning kit (QIAGEN). The sequence was confirmed, and a clone in which the amplified gene was inserted in the forward direction was selected (MFv2Casp3E/pDrive-9). The 1.7 Kb KpnI-XbaI fragment of this transit plasmid was cloned into pCMV/flox (Moeller et al., *supra*) at the respective sites (pCMVfloxMFv2Casp3E; shown in Fig. 1).

The following oligonucleotide primers were used for the PCR: MFv2Casp3E-f: 5'-CCACCATGGGGAGTAGCAAGAG-3', MFv2Casp3E-r: 5'-GGAATTCTTAGTCGAGTGCGTAGT-3'.

FIG. 2 is the sequence of a vector containing a floxed stop caspase-3 driven by a CMV promoter.

Example 2: *In vitro* confirmation of Dimerizable Conditional-Stop Caspase Construct

A fusion Caspase-3 derivative gene was subcloned from pSHMFv2Caspase3E by PCR and inserted into the multiple cloning site of pCMVflox as described herein.

The resulting plasmid was named pCMVfloxMFv2Csp3E, and the sequence was confirmed.

To confirm that the system works, the effect of the dimerizer, AP20187, was examined *in vitro* on cells that were transfected with either pCAN-Cre or pCMVflox, or cotransfected with both. 24 hours after transfection, cells were treated with the dimerizer AP20187, and 48 hours later cell-viability/dying cells were examined using a standard MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) assay. By MTT assay, cell viability was significantly reduced only in the group where both Cre-recombinase and transgene were transfected (Figure 6A).

To determine the extent of cell ablation, the co-transfected cells were compared with the original pSHMFv2Caspase3E in the presence of AP20187 using LIVE/DEAD analysis (Invitrogen). The number of dying cells and the decrease in cell viability was almost same in the co-transfected group as compared to the original plasmid transfection group (Figures 6B-6C). These results demonstrate that this plasmid works for *in vivo* spatiotemporal cell ablation.

Example 3: Generation of a Dimerizable Conditional-Stop Caspase Mouse

After microinjection of linearized plasmid into about 30-40 mouse oocytes using standard methods, twenty nine pups were born. The pups were genotyped by PCR, and Select seven male transgenic mice were identified as candidate founders (F_0) and bred.

An appropriate line was chosen, using the following criteria (F_1 analyses):

1 - genotyping PCR

2 - protein expression

a) Whole body scale distribution (this was determined by X-gal staining of whole embryos)

b) Detailed expression pattern in adults (this is determined, e.g., by beta-gal activity in each organ, using a luminometer, and anti-LacZ staining of each organ of interest)

3 - Functional screening

E.g., *in vitro* cell-death analyses

A summary of the F1 analysis is shown in Figure 7. The results indicated that lines B, D, and E are the best candidates. Actual expression of the transgene in each of these lines was confirmed by LacZ staining of F1 offspring; the results, shown in Table 1,

show that each of these lines was highly positive, though expression was not uniform throughout the animal.

Table 1 –Transgene Expression in Selected Lines

Tissue	Transgenic Line			
	B	**D**	**F**	wt
forebrain	**0.355**	**0.335**	0.282	0.151
brainstem	0.356	**0.598**	**0.427**	0.195
cerebrum	0.356	0.176	**0.921**	0.124
spinal cord	**0.553**	0.288	0.287	0.211
olfactory bulb	0.128	**0.805**	**0.558**	0.133
eye	0.308	0.19	**0.64**	0.208
temporal bone	**0.703**	0.227	**0.331**	0.119
salivary grand	0.191	0.194	**0.286**	0.182
tongue	**0.853**	**0.512**	**0.843**	0.165
lung	**0.399**	0.232	0.255	0.368
heart (atrial)	0.165	0.193	0.243	0.334
heart (ventricle)	0.277	0.324	**0.652**	0.193
diaphragm	**0.791**	0.256	**0.344**	0.253
esophagus	0.234	0.144	**0.755**	0.511
stomach	0.14	**0.355**	**0.547**	0.113
ileum	0.204	0.182	**0.302**	0.122
caecum	0.166	0.154	0.156	0.18
colon	0.228	0.24	0.28	0.135
liver	0.351	0.196	**0.419**	0.671
spleen	0.948	0.844	0.937	1.014
pancreas	0.331	**0.753**	**0.686**	0.165
adrenal gland	0.374	0.513	0.686	0.834
kidney	0.24	0.353	**0.96**	0.314
ovary	0.185	0.212	**0.384**	-
testis	-	-	-	0.176
bladder	0.175	0.153	0.189	0.491
muscle	**0.809**	0.259	**0.826**	0.303
skin	**0.773**	**0.817**	**1.19**	0.369
tail	0.58	**0.935**	**0.867**	0.167
Thymus	0.179	0.235	**0.941**	
gallbladder	0.11	0.131		
uterus		0.197		

Example 4: Generation of Double Transgenic Mice

A transgenic mouse with an inducible caspase gene was constructed as described above for targeted cell ablation. Double transgenic mice were obtained by breeding F_1 transgenic mice generated as described in Example 3 crossed using standard breeding methods with selected Cre-expressing mice, i.e.,

-Insulin-Cre: Diabetes model (targeting islet cells)

-pou4f3-Cre (also know as Brn3c): Hearing loss model (targeting cochlear sensory cell) (

-Rosa26-CreER: ubiquitous, for *in vitro* experiments

For example, crossing the STOP-flox-caspase3 mice to a Kr15-Cre mouse will make the hair cell follicles susceptible to FK506 analogue induced cell death. A number of Cre-expressing mice are available commercially, e.g., from Jackson Labs, Bar Harbor, Maine.

Expression of the caspase in cell-specific, time-specific manner is achieved in the mice by administering a dimerizing agent, e.g., AP20187. Figures 7A-C illustrate the expression of lac Z (7A) or the transgene (7B-C) in cells where transgene is driven by CMV promoter in the absence (7A) or presence (7B-C) of Cre recombinase. As examples, a pre-diabetic model and a mild hearing loss model were generated; both correlated *in vivo* to functional deficiency. A mouse with a ubiquitously expressed Cre recombinase was also used (rosa26-CreER), to verify transgene expression and function.

Cross with Cre recombinase: Rosa26-CreER

To provide a model for ready confirmation of the function of the conditional-stop dimerizable caspase transgene, the transgenic mice described herein (line F) were crossed with Rosa26-CreER mice. In vitro experiments on cells from the mice were contacted with tamoxifen to induce expression of the Cre recombinase, and the results, shown in Figure 13A, indicate successful recombination and expression of the transgene. A band at the expected size in Lane 1 indicates that the Cre mouse expresses Cre, and in Lane 2 demonstrates the presence of lacZ in the line F transgenic mouse. In the double transgenic mice, in the absence of tamoxifen (Tmx), both cre and lac Z are presence, as is the unrecombined 500 bp product (lane 3), while in the presence of tamoxifen the recombined product at 200 bp is present. The presence of some lacZ in the double transgenics in the presence of tmx indicates that the recombination is incomplete, which may be due to partial recombination with R26Cre/ER. These results confirm the confirm that *in vivo* recombination is taking place in the double transgenics.

Figure 13B is a schematic illustration of the genetic processes occurring in the double transgenic mice.

Cross with Cre recombinase: Brn3c-Cre

Auditory hair cells are the mechanosensory channel that transduce sound waves to action potentials. Since mammalian hair cells cannot spontaneously regenerate once lost, regenerative medicine for hearing loss would be of great importance, and it has been difficult to establish a reproducible model for ablation of hair cells. The transgenic mice described herein (line D) were mated with a hair cell-specific, Brn3c-Cre mouse from Doug Vetter (Xiang et al., Proc. Natl. Acad. Sci. U. S. A. 94(17):9445-50 (1997); Sage et al., Proc. Nat. Acad. Sci. 103(19):7345-7350 (2006)).

Detailed expression pattern in the auditory system including cochlea and brain was also determined by anti-V5 tag immunostaining in each of the three transgenic lines B, D, and F. One of the lines (line B) showed moderate expression in the cochlea, but almost no expression in the brain, while another line (line F) had ubiquitously high expression in the brain and cochlea. A brief summary of transgene expression in auditory systems is shown in Table 2.

Table 2 –Transgene Expression in Auditory and Brain Tissues of Selected Lines

Line	Tissue			
	IHC	OHC	spiral ganglion	brainstem/cortex
B	+	+	+++	-/-
D	++	+	±	+/-
F	+++	+	±	++/++

Inner hair cells (IHC); outer hair cells (OHC).

Thus, line B, D, or F can be chosen for a hair cell loss model (e.g., x Brn3c-Cre), and line B would be the best for a spiral ganglion loss model (e.g., x Ngn1-Cre).

In an *in vitro* experiment using an organ of Corti explant culture, the double transgenics showed 38.8% inner hair cell loss and 32.4% outer hair cell loss within 24 hours of incubation in the medium containing AP20187 suggesting rapid ablation occurred.

In vivo experiments were also performed. Animals at 6-8 weeks of age were administered AP20187 (10mg/kg ip) and analyzed six days later. A 60% decrease in the amplitude of the auditory brainstem response (ABR) as compared with same-animal measurements taken before treatment was also seen, indicative of hearing loss with 37.8% of inner hair cells lost after drug treatment (see Figs. 9A-9F). Distortion product otoacoustic emissions (DPOAE), responses generated when the cochlea is

stimulated simultaneously by two pure tone frequencies whose ratio is between 1.1 to 1.3, were significantly decreased in the treated animals, see Fig. 10A. ISO-DP, a measure of the threshold required to obtain a given level of response, was significantly increased in treated animals (Fig. 10B). Immunohistochemical experiments were consistent with this result. Mosaic loss of parvalbumin 3 (Pv3, a hair cell marker)-positive hair cells was seen in transgenics after AP20187 administration. Approximately 35 ~ 40% of inner hair cells and 15 % of outer hair cells were lost, as judged by Pv3 staining. Note that Musashi-1 staining depicts that pharyngeal processes of supporting cells was preserved, demonstrating ablation specifically occurred in hair cells. In addition, areas of dead cells (identified by a lack of Pv3 in hair cell plane) were partially covered by Msi1 staining, suggesting the presence of pharyngeal scarring in response to neighboring hair cell death. No remarkable changes were seen in the spiral ganglion.

Cross with Cre recombinase: Ins-Cre

Diabetes is cause by loss of insulin producing beta cells in the pancreas. These cells cannot be replaced by known techniques. A model for impaired glucose tolerance was constructed by crossing the transgenic mouse (line B) described herein with an Ins-Cre mouse (Jackson Labs). Partial loss of beta cells resulted in hyperplasia of existing islets of Langerhans and impaired glucose tolerance. This model has the characteristics of a pre-diabetic mouse.

The FK506 analogue AP20187 was administered by intraperitoneal (IP) injection. β-cell death was monitored in the animals by intraperitoneal glucose tolerance testing (IPGTT) using standard methodology. The results, shown in Figure 11A, demonstrate a partial loss of glucose control in the double transgenic animals treated with the dimerizer, similar to what is seen in humans with glucose intolerance, during the onset of Type 1 diabetes. This effect was more pronounced in female animals than in males, as shown in Figures 11B-C.

The effect on blood glucose levels was also evaluated using a standard glucose tolerance test (GTT). 30 minutes after a glucose challenge, a blood sample was obtained from the tail vein and a measurement of blood glucose was obtained with a glucose monitor. The results are shown in Figures 12A-B, and demonstrate that a significant increased in blood glucose levels was seen.

These results demonstrate that these mice recapitulate the partial loss of cells in the time course of degenerative diseases, and are thus a useful model for the onset of degenerative diseases, e.g., for evaluating the effect of interventions to treat such diseases.

OTHER EMBODIMENTS

It is to be understood that while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A transgenic non-human mammal having a recombinant nucleic acid molecule stably integrated into the genome of said mammal, said nucleic acid molecule comprising:

   (i) a promoter;

   (ii) downstream of said promoter, a conditional-STOP cassette comprising a coding region of a protein and polyadenylation signal, flanked on either side by a recombinase recognition site; and

   (iii) downstream of said conditional-STOP cassette, a sequence encoding a fusion protein comprising a caspase linked in frame with a FK Binding Protein (FKBP) or variant thereof, wherein said fusion protein is not expressed when said conditional-STOP cassette is present in the construct.

2. The transgenic non-human mammal of claim 1, wherein expression of a recombinase in a cell of said mammal results in expression of said fusion protein, and exposure of said mammal to an FKBP dimerizing agent results in death of said cells expressing said recombinase.

3. The non-human mammal of claim 1, wherein said recombinant nucleic acid molecule is operably linked to one or more regulatory sequences.

4. The non-human mammal of claim 3, wherein said recombinant nucleic acid molecule is operably linked to a promoter.

5. A cell isolated from the non-human mammal of claim 1.

6. The cell of claim 5, wherein said cell is a stem cell or a germ cell.

7. The transgenic non-human mammal of claim 1, wherein the mammal is a mouse.

8. The transgenic non-human mammal of claim 1, wherein the caspase is caspase 3.

9. A method for the production of a transgenic non-human mammal, comprising introduction of a recombinant nucleic acid molecule into a germ cell, an embryonic cell, or an egg cell, a recombinant nucleic acid molecule comprising:

   (i) a promoter;

(ii) downstream of said promoter, a conditional-STOP cassette including a coding region of a protein and polyadenylation signal, flanked on either side by a recombinase recognition site; and

(iii) downstream of said conditional-STOP cassette, a sequence encoding a fusion protein comprising a caspase linked in frame with a FK Binding Protein (FKBP) or variant thereof, wherein said fusion protein is not expressed when said conditional-STOP cassette is present in the construct.

10. .The method of claim 9, wherein said non-human mammal is a rodent.

11. The method of claim 10, wherein said rodent is a mouse.

12. The method of claim 9, further comprising crossing said transgenic non-human mammal with a second non-human mammal, wherein at least some of the cells of said second mammal express a recombinase that binds to and excises said stop sequence.

13. A vector, comprising:

(i) a promoter;

(ii) downstream of said promoter, a conditional-STOP cassette including a coding region of a protein and polyadenylation signal, flanked on either side by a recombinase recognition site; and

(iii) downstream of said conditional-STOP cassette, a sequence encoding a fusion protein comprising a caspase linked in frame with a FK Binding Protein (FKBP) or variant thereof, wherein said fusion protein is not expressed when said conditional-STOP cassette is present in the construct.

14. The vector of claim 13, further comprising one or more selection markers.

15. The vector of claim 14, wherein the selection marker is a negative selection marker.

16. The vector of claim 14, wherein the selection marker is an antibiotic resistance gene.

17. The vector of claim 16, wherein the antibiotic resistance gene is a neomycin resistance gene.

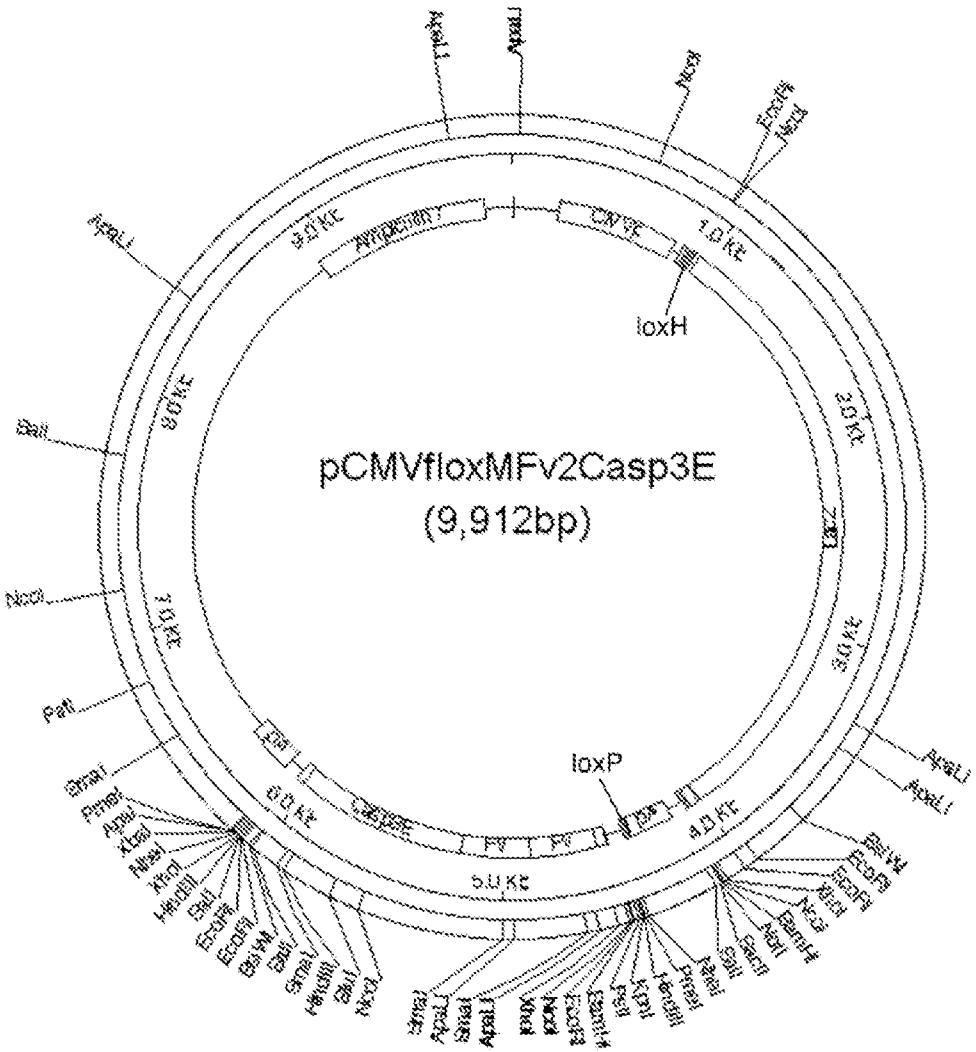
18. The vector of claim 17, wherein the neomycin resistance gene is PGK-Neo.

19. The vector of claim 13, wherein the vector is a viral vector.

20. The vector of claim 13, wherein the recombinase recognition sequence is a lox sequence.

21. The vector of claim 13, wherein the recombinase recognition sequence is a FLT sequence.

Figure 1



plasmid: pCMVfloxMFv2Casp3E size: 9,912bp

230-816 CMV promoter
861-880 T7 promoter
899-932 loxH
953-4009 LacZ
4022-4063 V5 epitope
4073-4089 6xHis
4171-4379 BGH polyA
4386-4416 loxP
4504-6075 MFv2Casp3E
  4504-4548 myrstoylation signal
  4551-4875 FKBP
  4876-5210 FKBP
  5211-6039 Caspase3 element
  6040-6075 HA-tag
6157-6383 BGH polyA
8916-9776 Ampicillin resist

Figure 2 SEQ ID NO: 1
Page 1 of 6

GTTAATTAAGGATCTCCCGATCCCCTATGGTGCACTCTCAGTACAATCTGCTCTGATGCCGCATAGTTA
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Figure 2 SEQ ID NO: 1
Page 2 of 6

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Figure 2 SEQ ID NO: 1

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Figure 2 SEQ ID NO: 1

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Figure 2 SEQ ID NO: 1
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Figure 2 SEQ ID NO: 1
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Figure 3, page 1 of 2

Figure 3 page 2 of 2

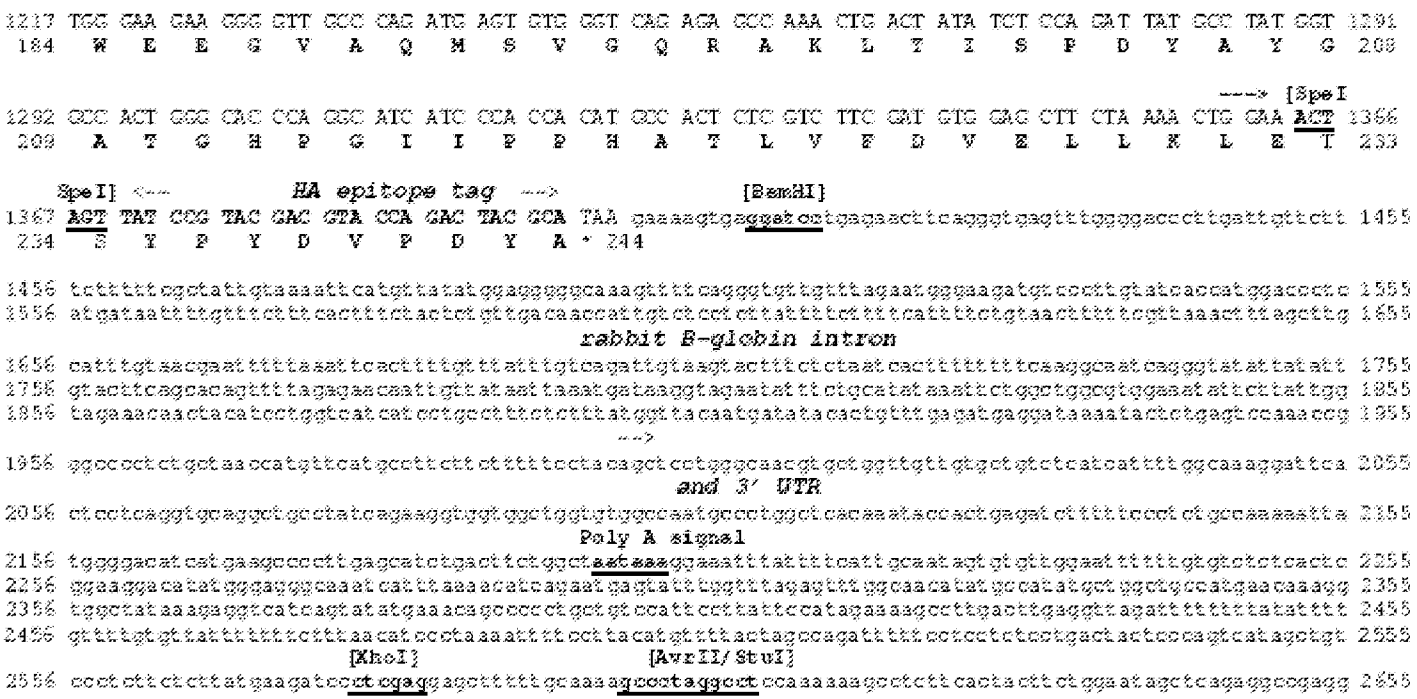

Figure 4

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CONSENSUS            MGV***TISPGDGRTFPKKGQTCVVHYTGML**GKK*DSSRDRNKPFKF**GKQEVI*G*FE**AAQM*LGQRAK***TP*VAYGATGHP*VIPP*AT*IFDV*L*NLE 16
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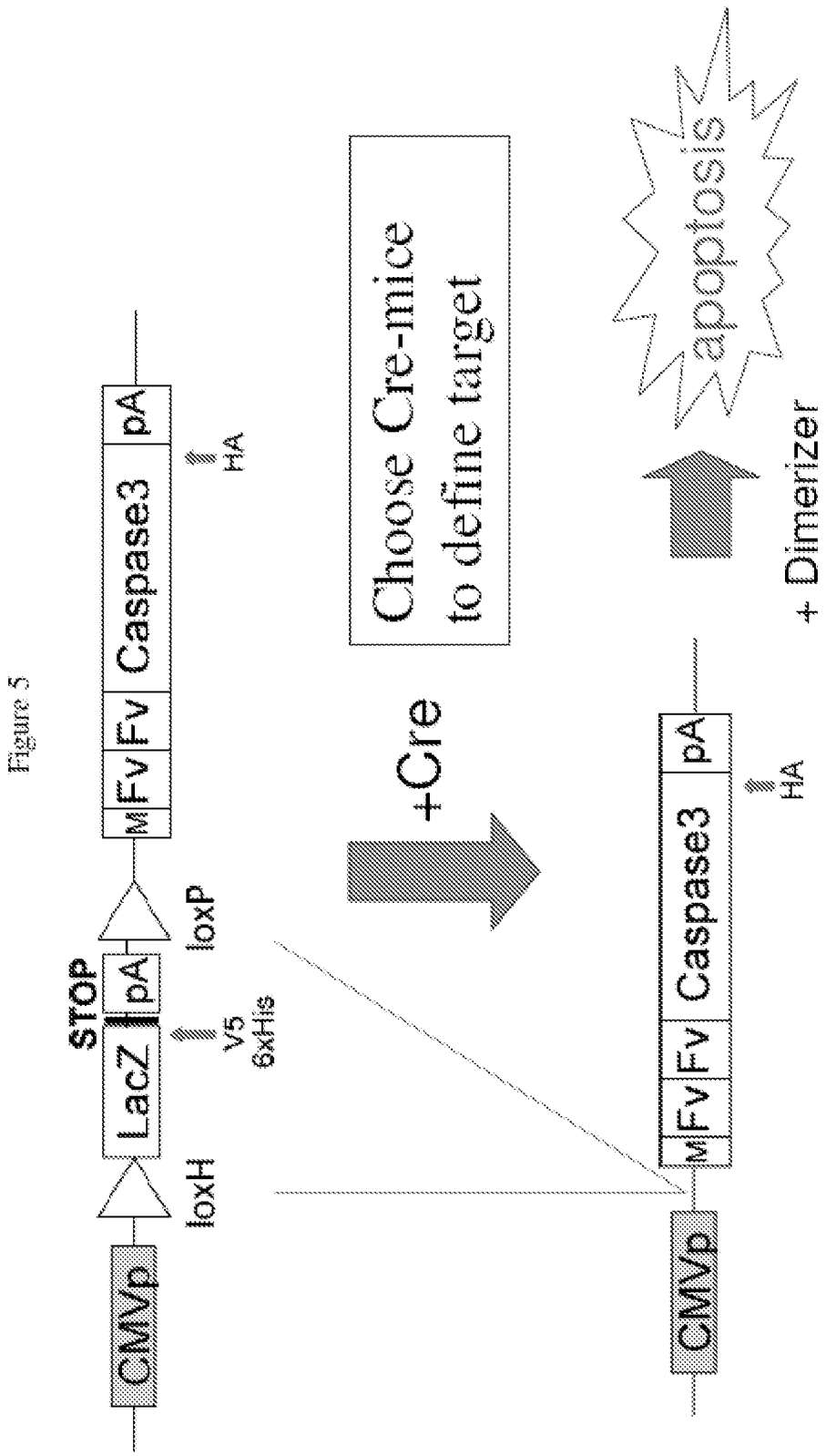
Figure 5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+Cre
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to define target
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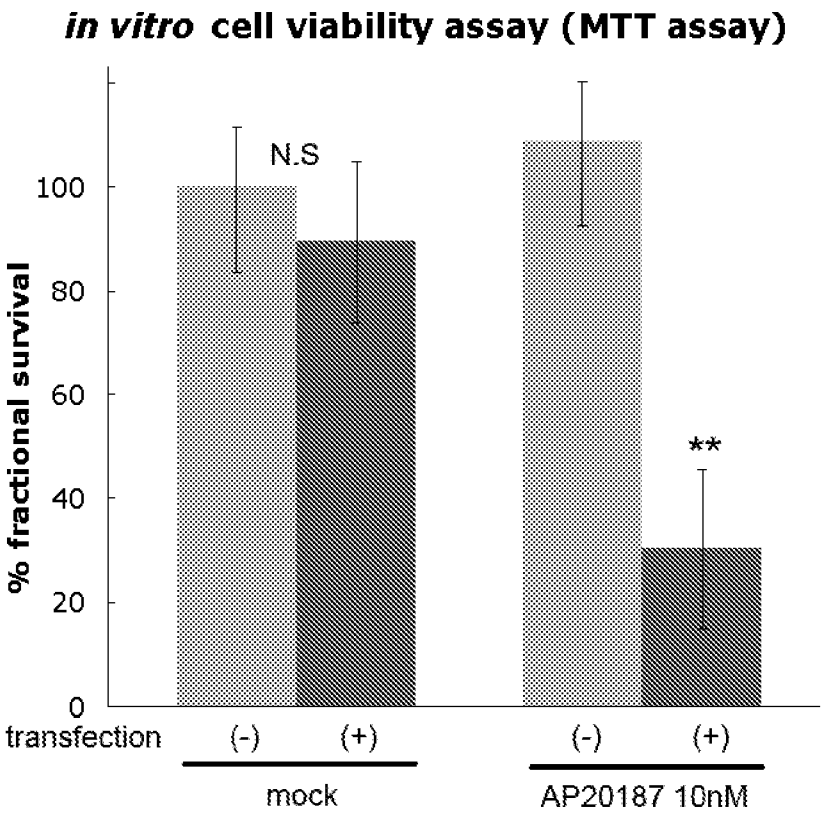
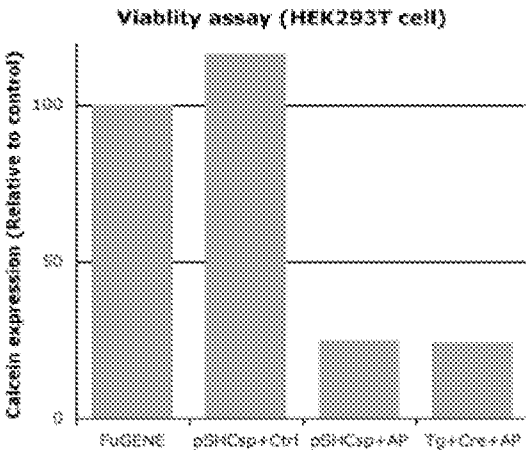
pA
HA
+ Dimerizer
apoptosis

Figure 6A





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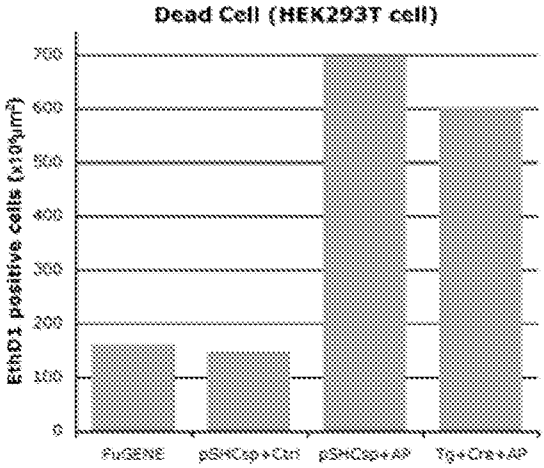
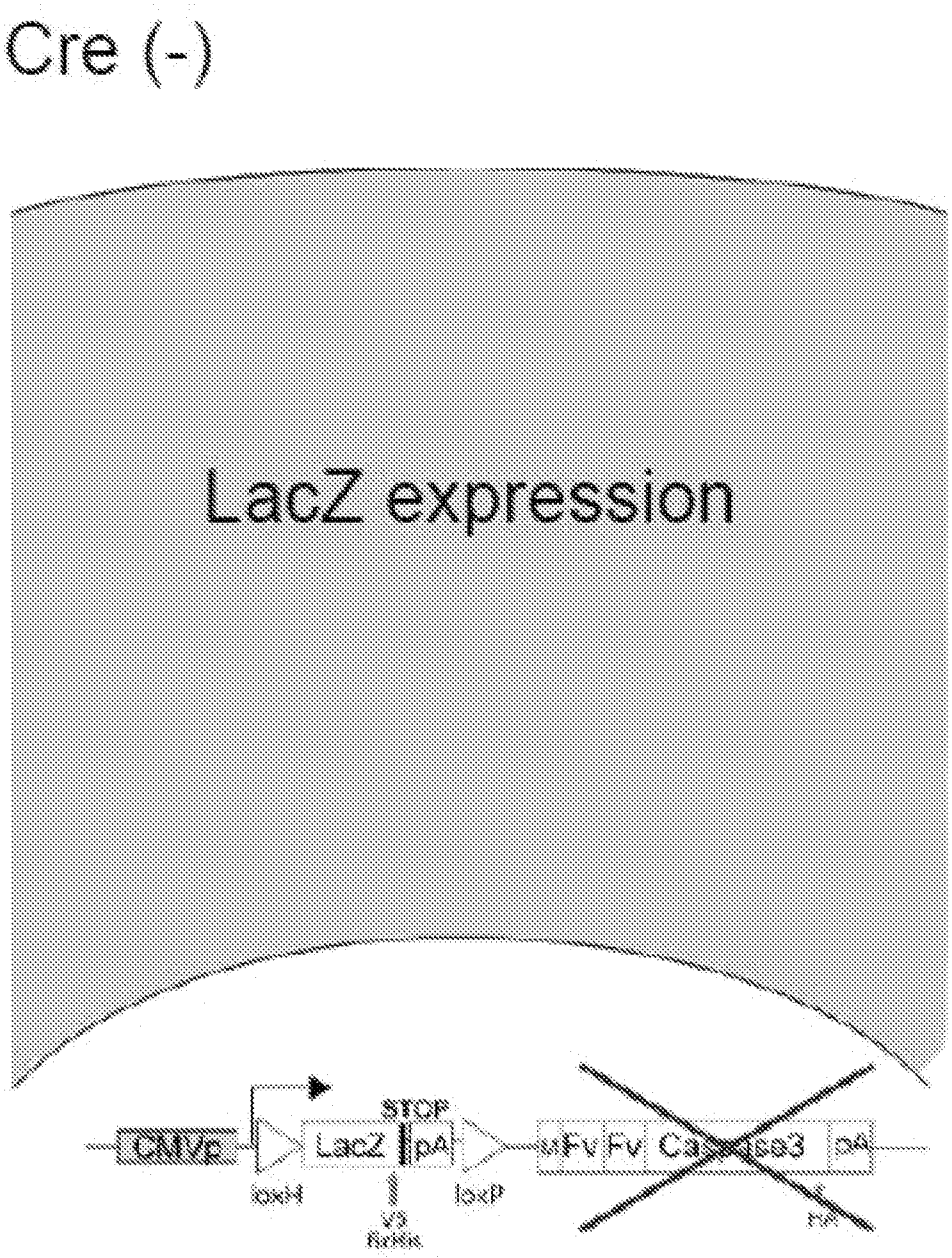


Figure 6C

Figure 7

Transgenic Line	A	B	C	D	E	F	G
1) F1-genotyping: to check the transgene inserted	+	+	+	+	-	+	-
2) F1-LacZ embryo: to check the protein distribution	-	+	-	+	-	+	
3) F1-whole body expression in adult: to see detailed organ specific protein distribution in adult	-	+	-	+	-	+	

Figure 8A



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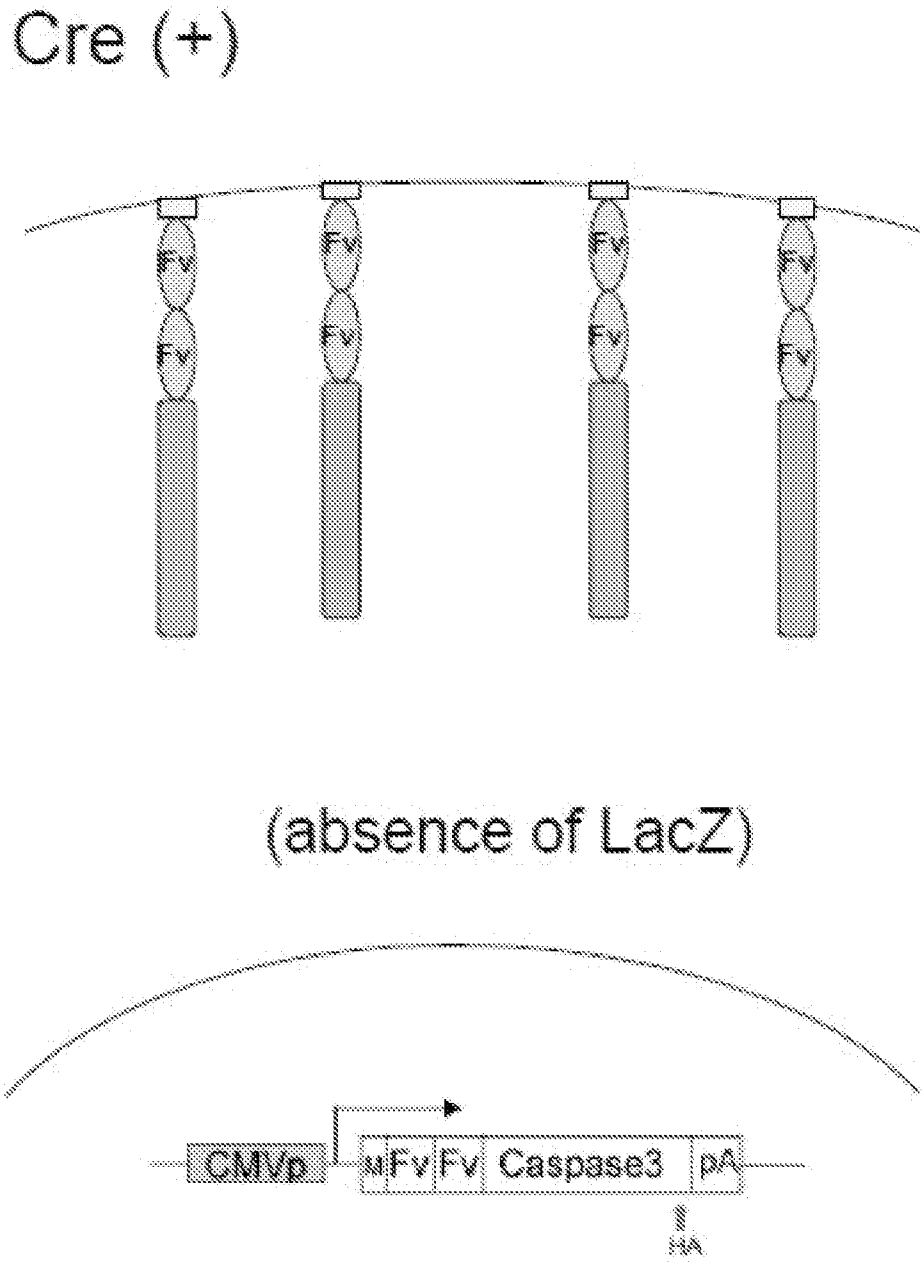
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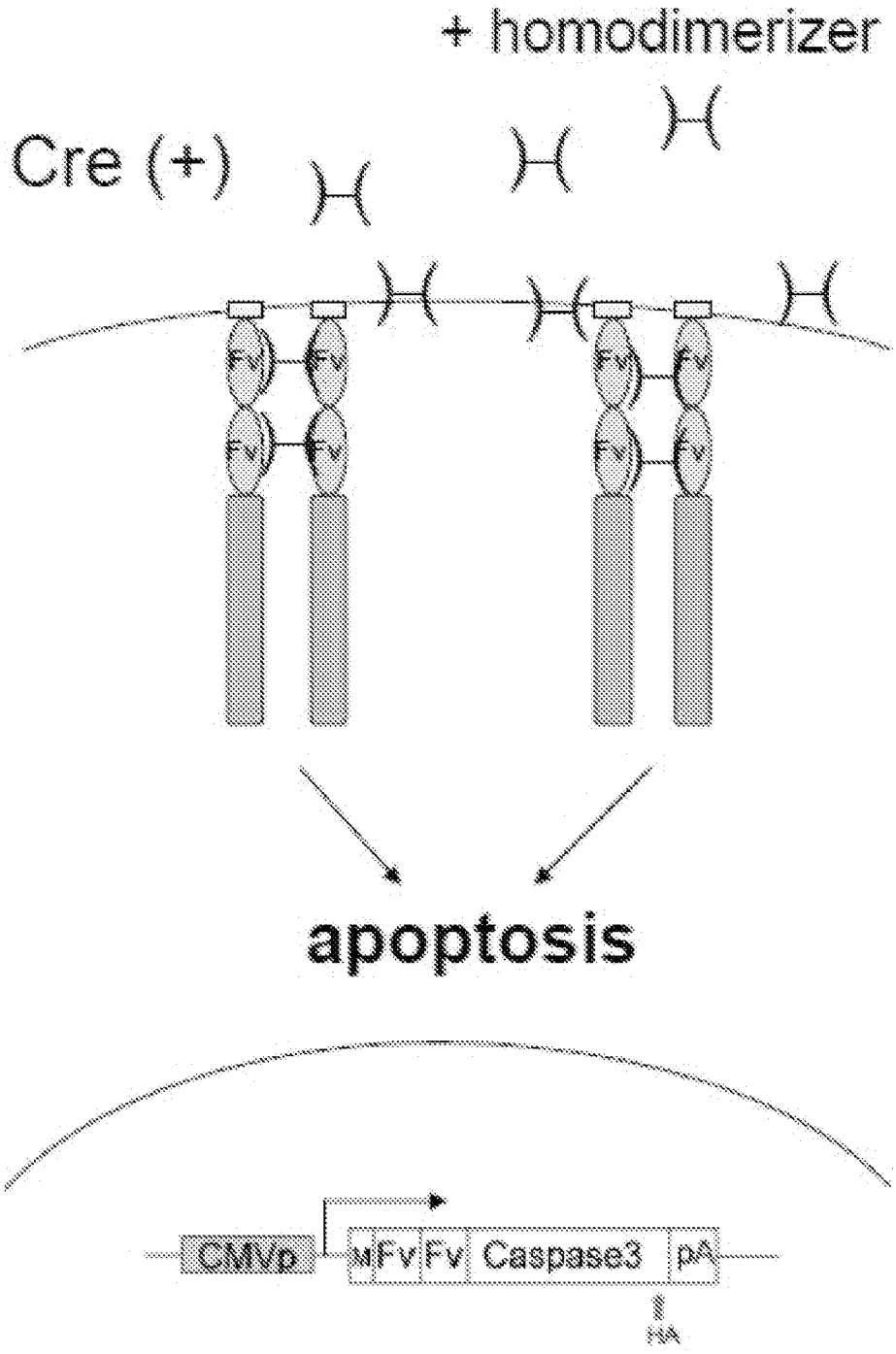
Fv
Fv
Fv
Fv
Fv
Fv
Fv
(absence of LacZ)
CMVp
M
Fv
Fv
Caspase3
pA
HA

Figure 8C



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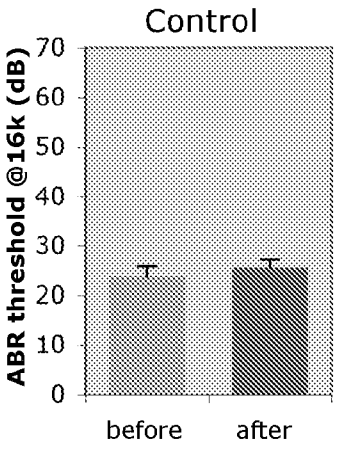

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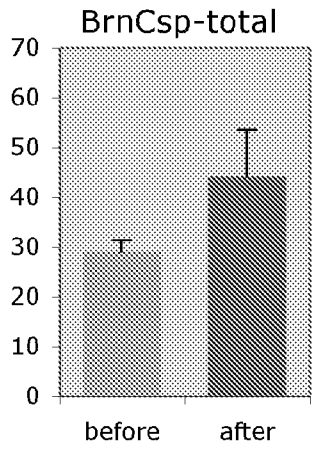

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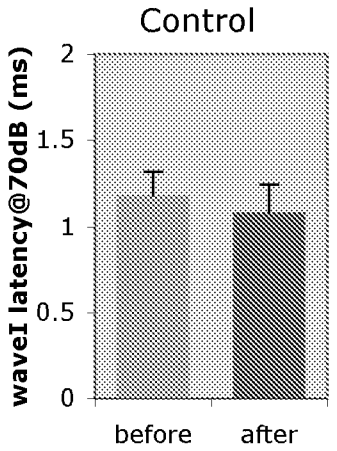

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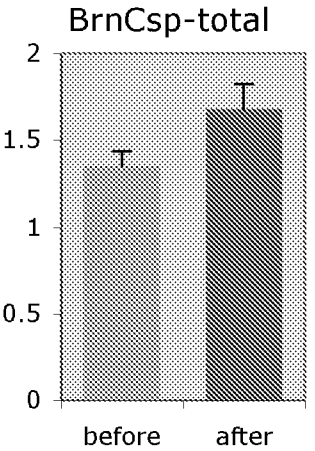

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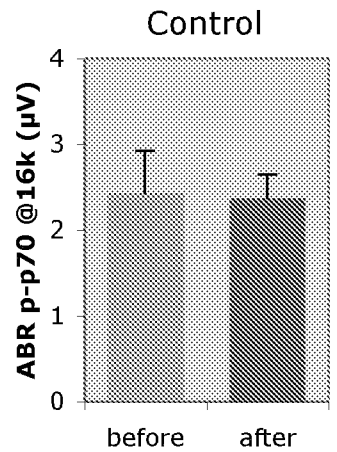

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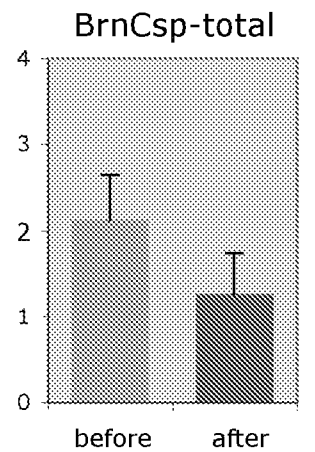


Figure 10A

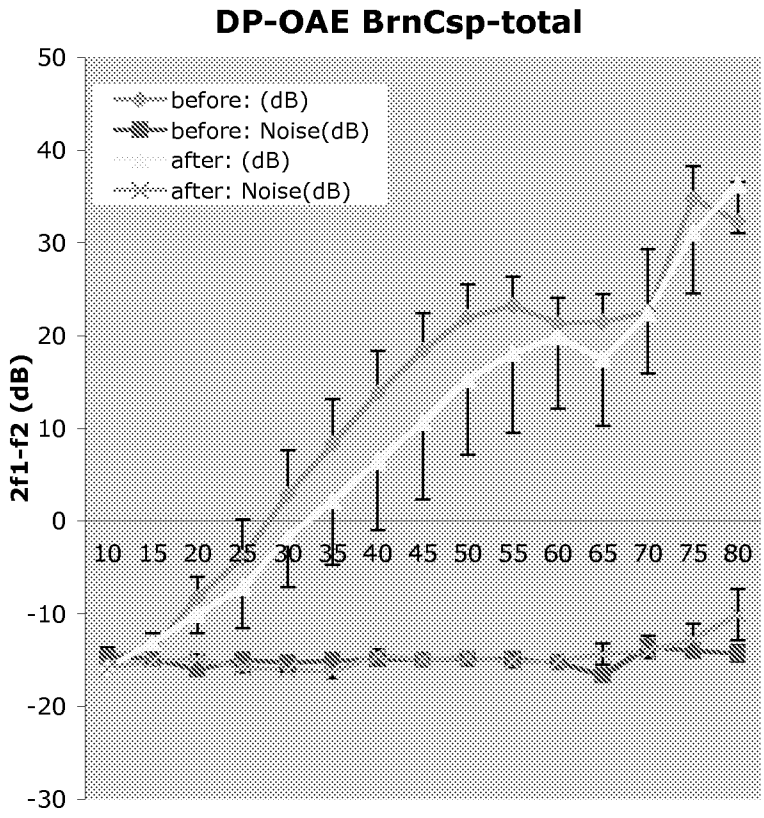


Figure 10B

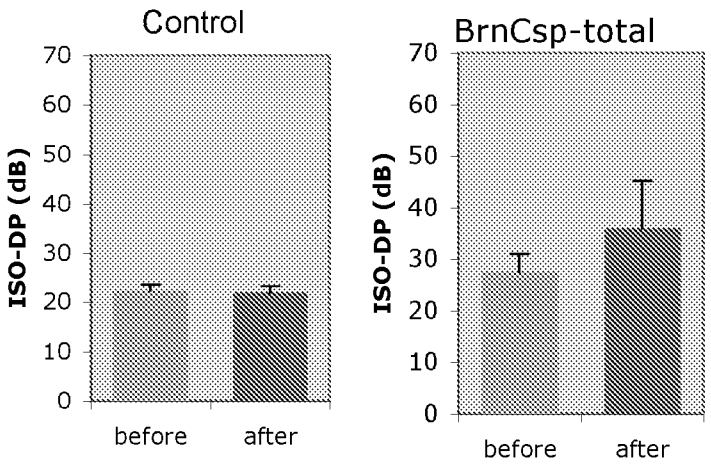


Figure 11A

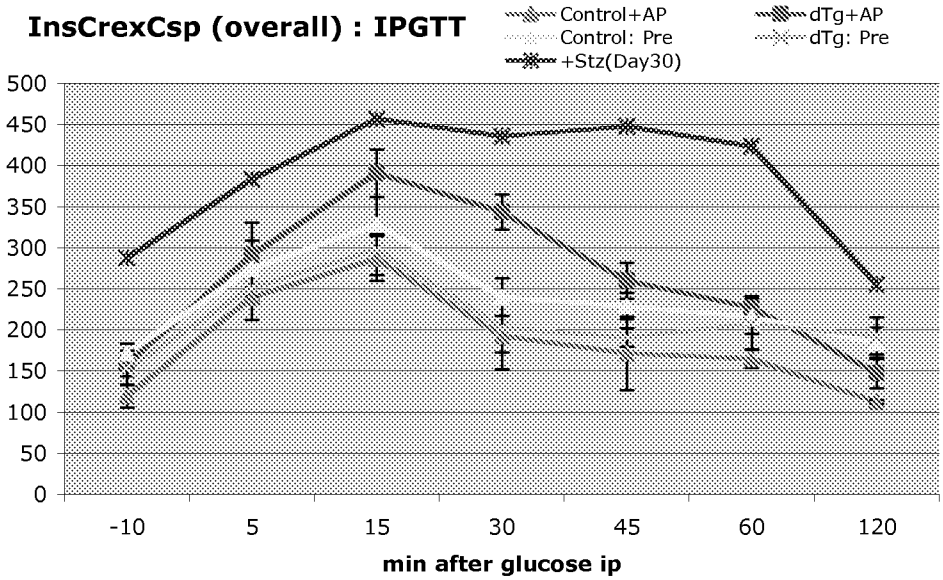
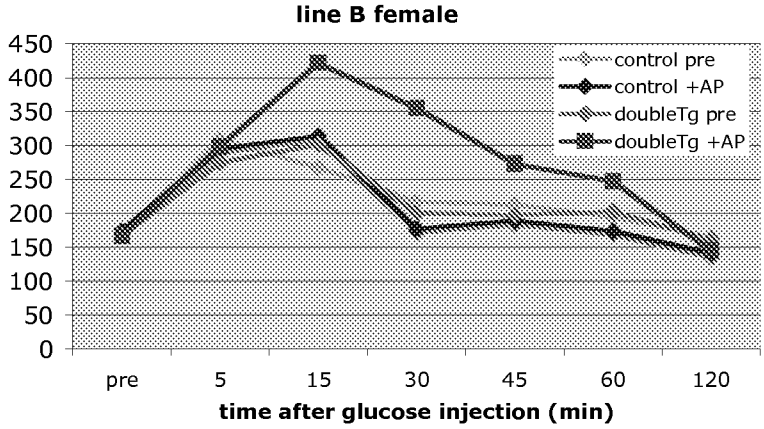


Figure 11B



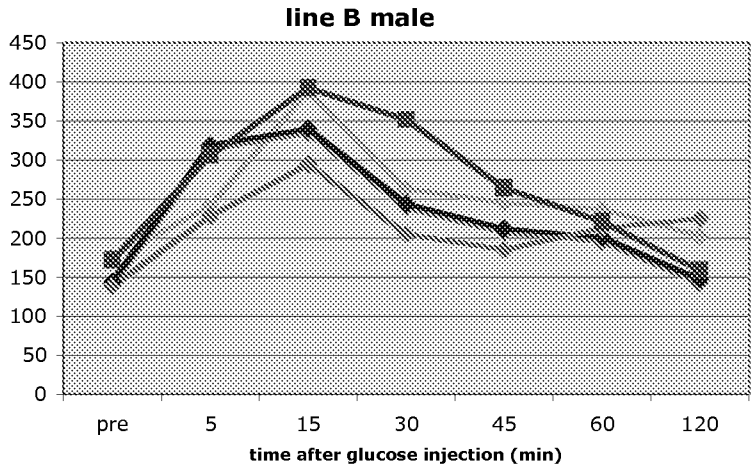
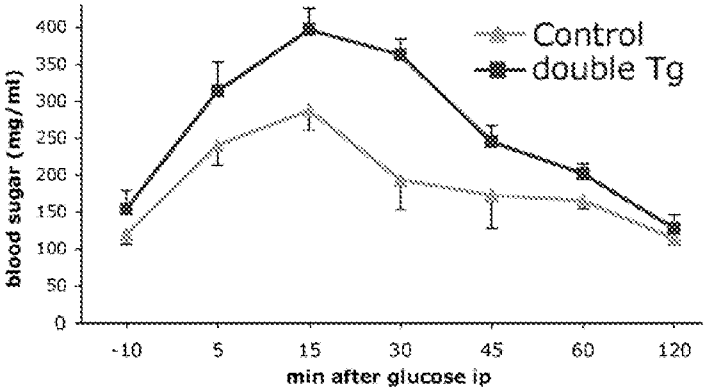


Figure 11C

Figure 12A



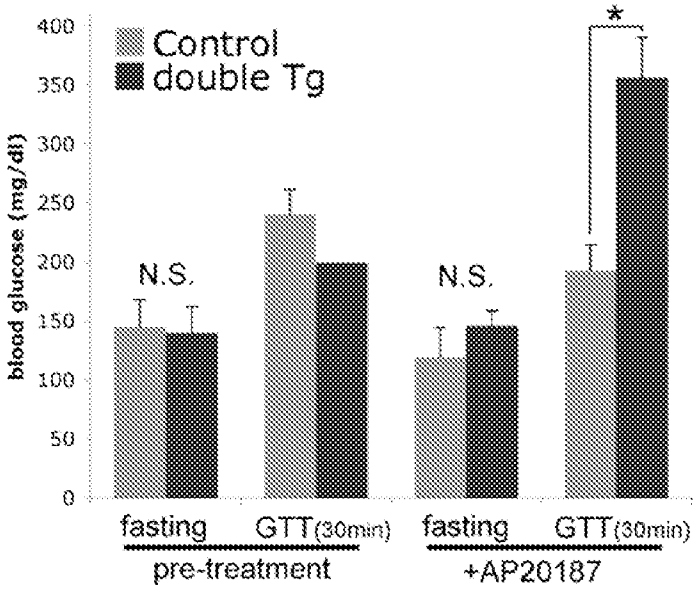


Figure 12B

Figure 13A

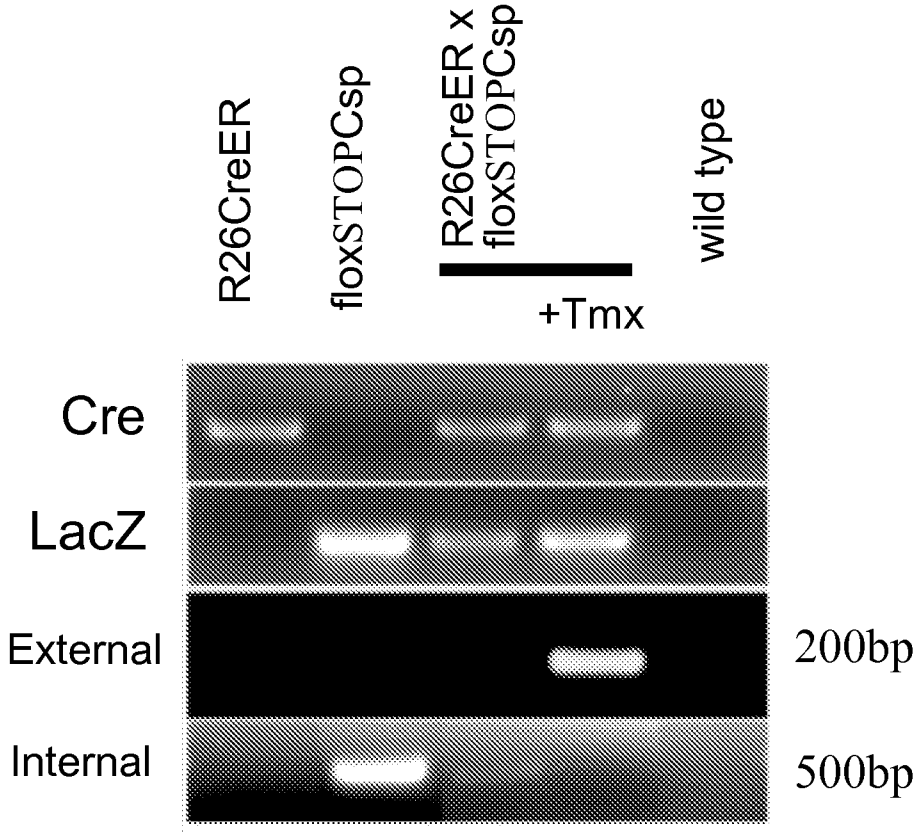
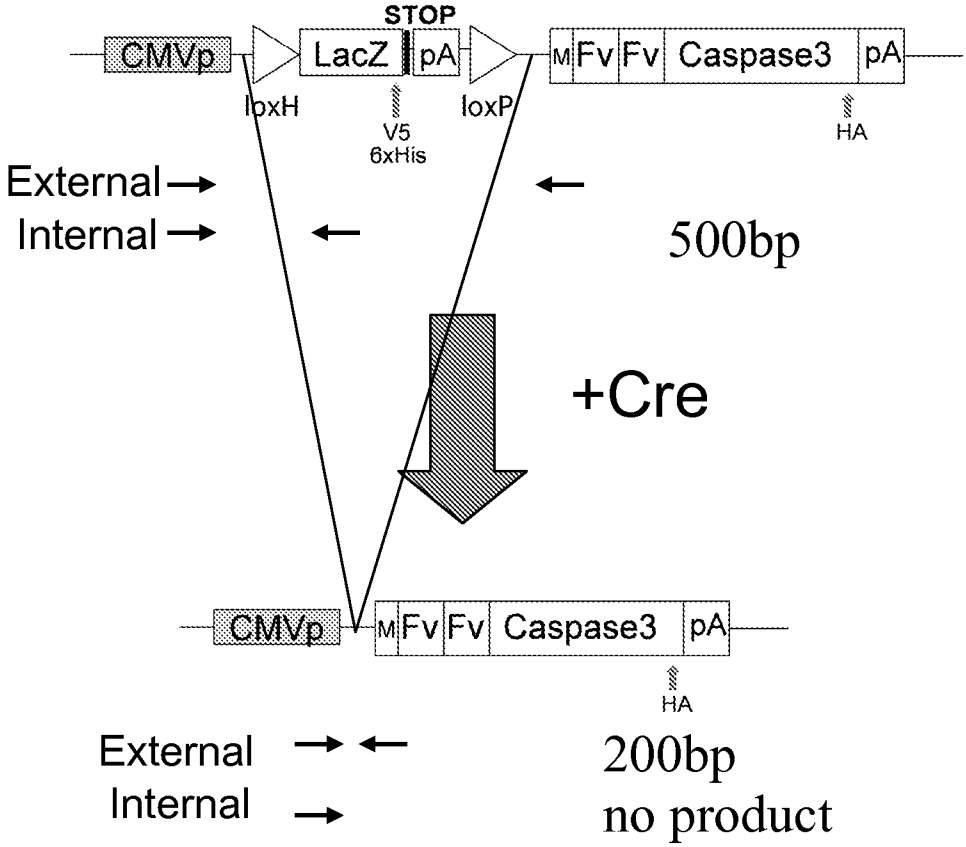

R26CreER
floxSTOPCsp
R26CreER x floxSTOPCsp
+Tmx
wild type
Cre
LacZ
External
Internal
200bp
500bp

Figure 13B


STOP
CMVp
LacZ
pA
M Fv Fv Caspase3
pA
loxH
V5
6xHis
loxP
HA
External
Internal
500bp
+Cre
CMVp
M Fv Fv Caspase3
pA
HA
External
Internal
200bp
no product

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/30780

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - C12N 15/64 (2009.01)
USPC - 435/91.4
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC - 435/91.4

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 435/91.4$, 320.1, 455, 462

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST(DB=PGPB,USPT,USOC,EPAB,JPAB), Google Scholar(conditional-STOP cassette, conditional STOP cassette, conditional STOP cassette caspase FK Binding Protein, conditional STOP cassette caspase "FK Binding Protein", cre lox caspase "FK Binding Protein", caspase "FK Binding Protein", FLP FRT caspase "FK Binding Protein")

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	LAKSO et al, Targeted oncogene activation by site-specific recombination in transgenic mice. PNAS, July 1992, vol 89, pp 6232-6236; especially Abstract; pg 6233, Fig 1	1-21
Y	WENCKER et al, A mechanistic role for cardiac myocyte apoptosis in heart failure. J. Clin. Invest. 2003, vol 111, pp 1497-1504; especially Abstract; pg 1498, Methods, Generation of FK-binding-protein.caspase-8 transgenic mice; pg 1499, right col, para 2-3; pg 1500, left col, para 1, pg 1503, right col, para 4' pg 1504, left col, para 1	1-21
Y	LUDWIG et al, Development of mammary adenocarcinomas by tissue-specific knockout of Brca2 in mice. Oncogene, 2001, vol 20, pp 3937-3948; especially Abstract; pg 3938, left col, para 3, right col, para 1; pg 3947, Cytogenetic analysis	5-6
Y	SAUER, Inducible Gene Targeting in Mice Using the Cre/lox System. METHODS: A Companion to Methods in Enzymology, 1998, vol 14, pp 381-392; especially pg 382, fig 1; pg 385, left col, para 2; pg 386, fig 3; pg 387, left col, para 2	14-18
Y	VENTURA et al, Cre-lox-regulated conditional RNA interference from transgenes. PNAS, 13 July 2004 (13.07.2004); vol 101, no 28, pp 10380-10385;especially pg 10381, Virus Generation and Infection.; pg 10382, fig 1E; pg 10381, Results, Generation of pSico and pSicoR	19
Y	JONKERS et al, Conditional Mouse Model of Sporadic Cancer. NATURE REVIEWS CANCER, APRIL 2002, vol 2, pp 251-265; especially pg 255, fig 2b	21

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 March 2009 (21.03.2009)	10 APR 2009
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (April 2007)