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(54) **NEW ALZHEIMER'S DISEASE ANIMAL MODEL**

NEUES TIERMODELL FÜR DIE ALZHEIMER-KRANKHEIT

NOUVEAU MODÈLE ANIMAL DE LA MALADIE D'ALZHEIMER

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(73) Proprietors:
- **INSERM (Institut National de la Santé et de la Recherche Médicale) 75013 Paris (FR)**
- **Université Paris-Saclay 91190 Saint-Aubin (FR)**
- **Commissariat à l'Energie Atomique et aux Energies Alternatives 75015 Paris (FR)**
- **Centre National de la Recherche Scientifique (C.N.R.S.) 75016 Paris (FR)**
- **Université de Paris 75006 Paris (FR)**

(72) Inventors:
- **CARTIER-LACAVE, Nathalie F-94276 Cedex Le Kremlin Bicetre (FR)**
- **BRAUDEAU, Jérôme F-94276 Le Kremlin Bicetre (FR)**
- **DEGLON, Nicole F-92265 Cedex Fontenay-aux-Roses (FR)**
- **HANTRAYE, Philippe F-92265 Cedex Fontenay-aux-Roses (FR)**
- **AUDRAIN, Mickael F-94276 Cedex Le Kremlin Bicetre (FR)**

(74) Representative: **Icosa 83 avenue Denfert-Rochereau 75014 Paris (FR)**

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Description

FIELD OF THE DISCLOSURE:

[0001] The invention also relates to a method for inducing the Alzheimer's disease in a rodent or a non-human primate, said method comprising the administration of at least one vector containing a nucleic acid sequence that encodes the APP protein and the PS1 protein wherein the vector is an adeno-associated virus (AAV) vector 9 or 10 and to a rodent or a non-human primate having the Alzheimer's disease obtained by said method.

BACKGROUND:

[0002] Alzheimer's disease (AD) is the most frequently encountered form of dementia (about 70% of dementia cases). With improved life expectancy, especially in developed countries, the incidence of dementia has dramatically increased and current forecasts speak in terms of a doubling of the number of persons affected every 20 years. In France, it is estimated that more than 850,000 people (with a majority of woman) are currently suffering from dementia, and around 225,000 new cases appear each year. AD is characterized by the accumulation of senile plaques (SP), neurofibrillary tangles (NFT), and selective synaptic and neuronal loss in plaques are composed of insoluble extracellular aggregates consisting mainly of amyloid β (Aβ) peptides derived from proteolytic cleavages of the amyloid precursor protein (APP). Genetic studies, together with the demonstration of a direct toxic effect of Aβ, led to the development of the amyloid cascade hypothesis to explain the Aβ-associated neurodegenerative process. Aβ rapidly aggregates to form amorphous and fibrillar oligomers, which then deposit to build senile plaques. A number of studies have provided evidence that βCTF and soluble Aβ oligomers are more toxic to cells than mature fibrils (Kayed et al., 2003) and these neurotoxic peptides are originally produced by the cleavage of APP.

[0003] Mutations in genes that encode APP or proteases that generate Aβ (PS1; PS2) are responsible for the familial forms (5% of cases) of AD (Selkoe et al., 2001).

[0004] Different AD animal models have been developed, most of them being transgenic mouse models obtained by transferring genes carrying mutations identified in familial AD including APP, PS1 and PS2 (Lee and Han, 2013). Although not perfect, these models offer a mean to gain knowledge on the physiopathology of AD but they also suffer from various limitations (expression of neurotoxic peptides from in utero development, associated compensatory effect, genetic drift in particular) which impair their use in research.

[0005] The use of viral vectors to develop experimental models would be a valuable breakthrough in the field. AAV vectors are attractive tools for gene transfer in the central nervous system (CNS) due to their lack of toxicity, their strong capacity to transduce neurons and to stably express recombinant proteins (for several years in rodents, dogs and primates). Viral vectors have already and are currently being used in several clinical trials in human patients worldwide (Cartier et al., 2009). The use of viral vectors to develop new animal models of neurodegenerative disorders is currently under investigation (Deglon and Hantraye, 2005). This strategy holds various advantages compared to classical transgenic approaches: viral vectors are versatile, highly flexible tools to perform in vivo studies and multiple genetic models can be created in a short period of time. High transduction efficiencies as well as robust and sustained transgene expression lead to the rapid appearance of functional and behavioral abnormalities and severe neurodegeneration. Targeted injections in different brain areas can be used to investigate the regional specificity of the neuropathology and eliminate potential side effects associated with a widespread overexpression of the transgene. Finally, models can be established in different mammalian species including large animals like dogs, pigs and non-human primates, thereby providing an opportunity to assess complex behavioral changes and perform longitudinal follow-up of neuropathological alterations by imaging. Lentiviral or AAV vectors were successfully injected in the brain of adult mice, rats or primates to create models of various neurodegenerative diseases such as Huntington's, Parkinson's, Machado-Joseph diseases (Kirik et al., 2002; Lo Bianco et al., 2002).

SUMMARY:

[0006] The inventors have now developed an efficient and powerful rodent or non-human primate model of Alzheimer's disease by using optimized APPsl and PS1 genes and Adeno-associated virus (AAV) vectors.

[0007] Disclosed herein is a vector comprising a nucleic acid sequence that encodes the APP protein and/or the PS 1 protein or variants thereof.

[0008] The invention relates to a method for inducing the Alzheimer's disease in a rodent or a non-human primate, said method comprising the administration of at least one vector containing a nucleic acid sequence that encodes the APP protein and the PS 1 protein wherein the vector is an adeno-associated virus (AAV) vector 9 or 10 and to a rodent or a non-human primate model having the Alzheimer's disease obtained by said method.

DETAILED DESCRIPTION:

Vectors

[0009] Disclosed herein is a vector comprising a nucleic acid sequence that encodes the APP protein and/or the PS1 protein or variants thereof.

[0010] In one embodiment, the vector discloses a nucleic acid sequence that encodes the APP protein and a nucleic acid sequence that encodes the PS1 protein.

[0011] In another embodiment, the vector may disclose any variant of the nucleic acid sequence which encodes for the APP protein and/or any variant of the nucleic acid sequence which encodes for the PS1 protein.

[0012] In another embodiment, the vector may disclose any variant of the nucleic acid sequence which encodes for any variant of the APP protein and/or any variant of the nucleic acid sequence which encodes for any variant of the PS1 protein.

[0013] In another embodiment, a vector comprising a nucleic acid sequence that encodes the APP protein or variants thereof and a vector comprising a nucleic acid sequence that encodes the PS1 protein or variants thereof.

[0014] As used herein, the term "APP" or "Amyloid Precursor Protein" denotes an integral membrane protein expressed in many tissues and concentrated in the synapses of neurons. Its primary function is not known, though it has been implicated as a regulator of synapse formation, neural plasticity and iron export. APP is best known as the precursor molecule whose proteolysis generates beta amyloid (Aβ), a 37 to 49 amino acid peptide whose amyloid fibrillar form is the primary component of amyloid plaques found in the brains of Alzheimer's disease patients. The cDNA sequence for APP is disclosed in Genbank under access number Gene ID: 351 and has the sequence SEQ ID NO:1 as described below:

ATGCTGCCCGGACTGGCTCTGCTGCTGCTGGCCGCTTGGACCGCCAGAGCC
CTGGAAGTGCCCACCGATGGCAATGCTGGCCTGCTGGCCGAGCCCCAGATCGCCA
TGTTCTGCGGCAGACTGAACATGCACATGAACGTGCAGAACGGCAAGTGGGACA
GCGACCCCAGCGGCACCAAGACCTGCATCGACACCAAAGAGGGCATCCTGCAGT
ATTGCCAGGAAGTGTACCCCGAGCTGCAGATCACCAACGTGGTGGAAGCCAACC

AGCCCGTGACCATCCAGAACTGGTGCAAGCGGGGCAGAAAGCAGTGCAAGACCC
ACCCCCACTTCGTGATCCCTTACCGGTGCCTGGTCGGAGAGTTCGTGTCCGACGC
5 CCTGCTGGTGCCCGACAAGTGCAAGTTCCTGCATCAGGAACGGATGGACGTCTGC
GAGACACATCTGCACTGGCACACCGTGGCCAAAGAGACATGCAGCGAGAAGTCC
ACCAACCTGCACGACTACGGCATGCTGCTGCCCTGCGGCATCGACAAGTTCCGGG
10 GCGTGGAATTCGTGTGCTGCCCCCTGGCCGAGGAATCCGACAACGTGGACAGCGC
CGACGCCGAAGAGGACGACAGCGACGTGTGGTGGGGCGGAGCCGACACCGATTA
CGCCGACGGCAGCGAGGACAAGGTCGTGGAAGTGGCTGAAGAGGAAGAGGTGG
15 CCGAGGTCGAAGAAGAGGAAGCCGACGACGACGAGGATGACGAGGACGGCGAC
GAAGTGGAAGAAGAAGCCGAGGAACCCTACGAGGAAGCCACCGAGCGGACCAC
CTCTATCGCCACCACCACCACAACCACTACCGAGAGCGTGGAAGAGGTGGTGCG
20 CGAAGTGTGCAGCGAGCAGGCCGAGACAGGCCCCTGCCGGGCCATGATCAGCCG
GTGGTACTTCGACGTGACCGAGGGCAAGTGCGCCCCCTTCTTCTATGGCGGCTGC
GGCGGCAACCGGAACAACTTCGACACCGAGGAATACTGCATGGCCGTGTGCGGC
25 AGCGCCATCCCTACCACAGCCGCCAGCACCCCCGACGCCGTGGACAAGTACCTGG
AAACCCCTGGCGACGAGAACGAGCACGCCCACTTCCAGAAGGCCAAAGAGCGGC
TGGAAGCCAAGCACCGCGAGCGGATGAGCCAGGTGATGAGAGAGTGGGAAGAG
30 GCCGAGAGACAGGCCAAGAACCTGCCCAAGGCCGACAAGAAAGCCGTGATCCAG
CACTTCCAGGAAAAGGTCGAAAGCCTGGAACAGGAAGCCGCCAACGAGCGGCAG
CAGCTGGTGGAAACCCACATGGCCAGAGTGGAAGCCATGCTGAACGACCGGCGG
35 AGACTGGCCCTGGAAAACTACATCACCGCCCTGCAGGCCGTGCCCCCCAGACCCA
GACACGTGTTCAACATGCTGAAGAAATACGTGCGGGCCGAGCAGAAGGACCGGC
AGCACACCCTGAAGCACTTCGAGCACGTGCGGATGGTGGACCCCAAGAAGGCCG
40 CCCAGATCCGCTCTCAGGTCATGACCCACCTGAGAGTGATCTACGAGAGAATGAA
CCAGAGCCTGAGCCTGCTGTACAATGTGCCCGCCGTGGCCGAAGAAATCCAGGA
CGAGGTGGACGAGCTGCTGCAGAAAGAGCAGAACTACAGCGACGACGTGCTGGC
45 CAACATGATCAGCGAGCCCCGGATCAGCTACGGCAACGACGCCCTGATGCCCAG
CCTGACCGAGACAAAGACCACCGTGGAACTGCTGCCCGTGAACGGCGAGTTCAG
CCTGGACGACCTGCAGCCCTGGCACAGCTTTGGCGCTGATAGCGTGCCCGCCAAC
50 ACCGAGAACGAGGTGGAACCCGTGGACGCCAGACCTGCCGCCGACAGAGGCCTG
ACCACAAGACCTGGCAGCGGCCTGACCAACATCAAGACCGAAGAGATCAGCGAA
GTGAACCTGGACGCCGAGTTCCGGCACGACAGCGGCTACGAGGTGCACCACCAG
55 AAACTGGTGTTCTTCGCCGAGGACGTGGGCAGCAACAAGGGCGCCATCATCGGC
CTGATGGTCGGAGGCGTGGTGATCGCCACCGTGATCATCATCACCCTGGTGATGC

TGAAAAAGAAGCAGTACACCAGCATCCACCACGGCGTGGTCGAAGTGGACGCCG
CTGTGACCCCCGAGGAACGGCACCTGAGCAAGATGCAGCAGAACGGCTACGAGA
ACCCCACCTACAAGTTCTTCGAGCAGATGCAGAACTGA.

[0015] The protein sequence of the APP protein has the sequence SEQ ID NO: 2 as described below:

MLPGLALLLLAAWTARALEVPTDGNAGLLAEPQIAMFCGRLNMHMNVQNG
KWDSDPSGTKTCIDTKEGILQYCQEVYPELQITNVVEANQPVTIQNWCKRGRKQCKT
HPHFVIPYRCLVGEFVSDALLVPDKCKFLHQERMDVCETHLHWHTVAKETCSEKSTN
LHDYGMLLPCGIDKFRGVEFVCCPLAEESDNVDSADAEEDDSDVWWGGADTDYAD
GSEDKVVEVAEEEEVAEVEEEADDDEDDEDGDEVEEEAEEPYEEATERTTSIATTTT
TTTESVEEVVREVCSEQAETGPCRAMISRWYFDVTEGKCAPFFYGGCGGNRNNFDTE
EYCMAVCGSAIPTTAASTPDAVDKYLETPGDENEHAHFQKAKERLEAKHRERMSQV
MREWEEAERQAKNLPKADKKAVIQHFQEKVESLEQEAANERQQLVETHMARVEAM
LNDRRRLALENYITALQAVPPRPRHVFNMLKKYVRAEQKDRQHTLKHFEHVRMVDP
KKAAQIRSQVMTHLRVIYERMNQSLSLLYNVPAVAEEIQDEVDELLQKEQNYSDDVL
ANMISEPRISYGNDALMPSLTETKTTVELLPVNGEFSLDDLQPWHSFGADSVPANTEN
EVEPVDARPAADRGLTTRPGSGLTNIKTEEISEVNLDAEFRHDSGYEVHHQKLVFFAE
DVGSNKGAIIGLMVGGVVIATVIIITLVMLKKKQYTSIHHGVVEVDAAVTPEERHLSK
MQQNGYENPTYKFFEQMQN.

[0016] In another embodiment, the APP used is the APP (SEQ ID NO: 2) with the Swedish and London mutations (APPsl) which has the following protein sequence (SEQ ID NO: 3):

MLPGLALLLLAAWTARALEVPTDGNAGLLAEPQIAMFCGRLNMHMNVQNG
KWDSDPSGTKTCIDTKEGILQYCQEVYPELQITNVVEANQPVTIQNWCKRGRKQCKT
HPHFVIPYRCLVGEFVSDALLVPDKCKFLHQERMDVCETHLHWHTVAKETCSEKSTN
LHDYGMLLPCGIDKFRGVEFVCCPLAEESDNVDSADAEEDDSDVWWGGADTDYAD
GSEDKVVEVAEEEEVAEVEEEADDDEDDEDGDEVEEEAEEPYEEATERTTSIATTTT
TTTESVEEVVREVCSEQAETGPCRAMISRWYFDVTEGKCAPFFYGGCGGNRNNFDTE
EYCMAVCGSAIPTTAASTPDAVDKYLETPGDENEHAHFQKAKERLEAKHRERMSQV
MREWEEAERQAKNLPKADKKAVIQHFQEKVESLEQEAANERQQLVETHMARVEAM
LNDRRRLALENYITALQAVPPRPRHVFNMLKKYVRAEQKDRQHTLKHFEHVRMVDP

KKAAQIRSQVMTHLRVIYERMNQSLSLLYNVPAVAEEIQDEVDELLQKEQNYSDDVL
ANMISEPRISYGNDALMPSLTETKTTVELLPVNGEFSLDDLQPWHSFGADSVPANTEN
EVEPVDARPAADRGLTTRPGSGLTNIKTEEISEVKMDAEFRHDSGYEVHHQKLVFFA
EDVGSNKGAIIGLMVGGVVIATVIVITLVMLKKKQYTSIHHGVVEVDAAVTPEERHL
SKMQQNGYENPTYKFFEQMQN.

[0017] As used herein, the term "PS1" or "Presenilin 1" denotes a protein encoded by the PSEN1 gene. Presenilin 1 is one of the four core proteins in presenilin complex, which mediate the regulated proteolytic events of several proteins in the cell, including gamma secretase. Gamma-secretase is considered to play a strong role in generation of beta amyloid, accumulation of which is related to the onset of Alzheimer's disease, from the beta-amyloid precursor protein. The cDNA sequence for PS1 is disclosed in Genbank under access number Gene ID: 5663 and code for the following protein sequence (SEQ ID NO:4):

MTELPAPLSYFQNAQMSEDNHLSNTVRSQNDNRERQEHNDRRSLGHPEPLSN
GRPQGNSRQVVEQDEEEDEELTLKYGAKHVIMLFVPVTLCMVVVVATIKSVSFYTRK
DGQLIYTPFTEDTETVGQRALHSILNAAIMISVIVVLTILLVVLYKYRCYKVIHAWLIIS
SLLLLFFFSFIYLGEVFKTYNVAVDYITVALLIWNFGVVGMISIHWKGPLRLQQAYLI
MISALMALVFIKYLPEWTAWLILAVISVYDLVAVLCPKGPLRMLVETAQERNETLFP
ALIYSSTMVWLVNMAEGDPEAQRRVSKNSKYNAESTERESQDTVAENDDGGFSEEW
EAQRDSHLGPHRSTPESRAAVQELSSSILAGEDPEERGVKLGLGDFIFYSVLVGKASA
TASGDWNTTIACFVAILIGLCLTLLLLAIFKKALPALPISITFGLVFYFATDYLVQPFMD
QLAFHQFYI.

[0018] In one embodiment, the PS1 protein used may be modified (PS1 M 146L) and may have the protein sequence sequence (SEQ ID NO: 5) as described below:

MTELPAPLSYFQNAQMSEDNHLSNTVRSQNDNRERQEHNDRRSLGHPEPLSN
GRPQGNSRQVVEQDEEEDEELTLKYGAKHVIMLFVPVTLCMVVVVATIKSVSFYTRK
DGQLIYTPFTEDTETVGQRALHSILNAAIMISVIVVMTILLVVLYKYRCYKVIHAWLII
SSLLLLFFFSFIYLGEVFKTYNVAVDYITVALLIWNFGVVGMISIHWKGPLRLQQAYLI
MISALMALVFIKYLPEWTAWLILAVISVYDLVAVLCPKGPLRMLVETAQERNETLFP
ALIYSSTMVWLVNMAEGDPEAQRRVSKNSKYNAESTERESQDTVAENDDGGFSEEW
EAQRDSHLGPHRSTPESRAAVQELSSSILAGEDPEERGVKLGLGDFIFYSVLVGKASA

TASGDWNTTIACFVAILIGLCLTLLLLAIFKKALPALPISITFGLVFYFATDYLVQPFMD
QLAFHQFYI.

[0019] In another embodiment, the vector discloses a nucleic acid sequence that encodes the APP protein and/or the PS1 or PS2 proteins or variants thereof.

[0020] As used herein, the term "PS2" or "Presenilin 2" denotes a protein encoded by the PSEN2 gene. Presenilin 2 is one of the four core proteins in presenilin complex, which mediate the regulated proteolytic events of several proteins

in the cell, including gamma secretase. Gamma-secretase is considered to play a strong role in generation of beta amyloid, accumulation of which is related to the onset of Alzheimer's Disease, from the beta-amyloid precursor protein. The cDNA sequence for PS2 is disclosed in Genbank under access number Gene ID: 5664 and code for the following protein (SEQ ID NO:6):

MLTFMASDSEEEVCDERTSLMSAESPTPRSCQEGRQGPEDGENTAQWRSQEN
EEDGEEDPDRYVCSGVPGRPPGLEEELTLKYGAKHVIMLFVPVTLCMIVVVATIKSVR
FYTEKNGQLIYTPFTEDTPSVGQRLLNSVLNTLIMISVIVVMTIFLVVLYKYRCYKFIH
GWLIMSSLMLLFLFTYIYLGEVLKTYNVAMDYPTLLLTVWNFGAVGMVCIHWKGPL
VLQQAYLIMISALMALVFIKYLPEWSAWVILGAISVYDLVAVLCPKGPLRMLVETAQ
ERNEPFPALIYSSAMVWTVGMAKLDPSSQGALQLPYDPEMEEDSYDSFGEPSYPEVF
EPPLTGYPGEELEEEEERGVKLGLGDFIFYSVLVGKAAATGSGDWNTTLACFVAILIG
LCLTLLLLAVFK KALPALPISITFGLIFYFST DNLVRPFMDT LASHQLYI.

[0021] In one embodiment, the vector discloses a nucleic acid sequence that encodes the APP protein and a nucleic acid sequence that encodes the PS2 protein.

[0022] In one embodiment, the vector of the invention discloses a nucleic acid sequence that encodes the APP protein, a nucleic acid sequence that encodes the PS1 protein and a nucleic acid sequence that encodes the PS2 protein.

[0023] In another embodiment, the vector may disclose any variant of the nucleic acid sequence which encodes for the APP protein and/or any variant of the nucleic acid sequence which encodes for the PS1 protein and/or variant of the nucleic acid sequence which encodes for the PS2 protein.

[0024] In another embodiment, the vector may disclose any variant of the nucleic acid sequence which encodes for any variant of the APP protein and/or any variant of the nucleic acid sequence which encodes for any variant of the PS1 protein and/or any variant of the nucleic acid sequence which encodes for any variant of the PS2 protein.

[0025] The variants include, for instance, naturally-occurring variants due to allelic variations between individuals (e.g., polymorphisms), alternative splicing forms, etc. The term variant also includes genes sequences of the disclosure from other sources or organisms. Variants are preferably substantially homologous to sequences according to the disclosure, i.e., exhibit a nucleotide sequence identity of typically at least about 75%, preferably at least about 85%, more preferably at least about 90%, more preferably at least about 95% with sequences of the disclosure. Variants of the genes of the disclosure also include nucleic acid sequences, which hybridize to a sequence as defined above (or a complementary strand thereof) under stringent hybridization conditions. Typical stringent hybridisation conditions include temperatures above 30° C, preferably above 35°C, more preferably in excess of 42°C, and/or salinity of less than about 500 mM, preferably less than 200 mM. Hybridization conditions may be adjusted by the skilled person by modifying the temperature, salinity and/or the concentration of other reagents such as SDS, SSC, etc.

[0026] In one embodiment, the vector use according to the invention discloses a viral vector.

[0027] Gene delivery viral vectors useful in the practice of the present disclosure can be constructed utilizing methodologies well known in the art of molecular biology. Typically, viral vectors carrying transgenes are assembled from polynucleotides encoding the transgene, suitable regulatory elements and elements necessary for production of viral proteins which mediate cell transduction.

[0028] The terms "gene transfer" or "gene delivery" refer to methods or systems for reliably inserting foreign DNA into host cells. Such methods can result in transient expression of non-integrated transferred DNA, extrachromosomal replication and expression of transferred replicons (e. g. episomes), or integration of transferred genetic material into the genomic DNA of host cells.

[0029] Such recombinant viruses may be produced by techniques known in the art, such as by transfecting packaging cells or by transient transfection with helper plasmids or viruses. Typical examples of virus packaging cells include PA317 cells, PsiCRIP cells, GPenv+ cells, 293 cells, etc. Detailed protocols for producing such replication-defective recombinant viruses may be found for instance in WO95/14785, WO96/22378, US5,882,877, US6,013,516, US4,861,719, US5,278,056 and WO94/19478.

[0030] The viral vector is an adeno-associated virus (AAV) vectors.

[0031] The AAV vector is, AAV9 or AAV10.

[0032] By an "AAV vector" is meant a vector derived from an adeno-associated virus serotype, including without limitation, AAV-1, AAV-2, AAV-3, AAV-4, AAV-5, AAV6, etc. AAV vectors can have one or more of the AAV wild-type genes deleted in whole or part, preferably the rep and/or cap genes, but retain functional flanking ITR sequences. Functional ITR sequences are necessary for the rescue, replication and packaging of the AAV virion. Thus, an AAV

vector is defined herein to include at least those sequences required in cis for replication and packaging (e. g., functional ITRs) of the virus. ITRs don't need to be the wild-type nucleotide sequences, and may be altered, e. g , by the insertion, deletion or substitution of nucleotides, so long as the sequences provide for functional rescue, replication and packaging. AAV expression vectors are constructed using known techniques to at least provide as operatively linked components in the direction of transcription, control elements including a transcriptional initiation region, the DNA of interest (i.e. the nucleic acid sequences of the description) and a transcriptional termination region.

[0033] The control elements are selected to be functional in a mammalian cell. The resulting construct which contains the operatively linked components is bounded (5' and 3') with functional AAV ITR sequences. By "adeno-associated virus inverted terminal repeats" or "AAVITRs" is meant the art-recognized regions found at each end of the AAV genome which function together in cis as origins of DNA replication and as packaging signals for the virus. AAV ITRs, together with the AAV rep coding region, provide for the efficient excision and rescue from, and integration of a nucleotide sequence interposed between two flanking ITRs into a mammalian cell genome. The nucleotide sequences of AAV ITR regions are known. As used herein, an "AAV ITR" does not necessarily comprise the wild-type nucleotide sequence, but may be altered, e. g., by the insertion, deletion or substitution of nucleotides. Additionally, the AAV ITR may be derived from any of several AAV serotypes, including without limitation, AAV-1, AAV-2, AAV-3, AAV-4, AAV-5, AAV6, etc. Furthermore, 5' and 3' ITRs which flank a selected nucleotide sequence in an AAV vector need not necessarily be identical or derived from the same AAV serotype or isolate, so long as they function as intended, i. e., to allow for excision and rescue of the sequence of interest from a host cell genome or vector, and to allow integration of the heterologous sequence into the recipient cell genome when AAV Rep gene products are present in the cell. Additionally, AAV ITRs may be derived from any of several AAV serotypes, including without limitation, AAV-1, AAV-2, AAV-3, AAV-4, AAV 5, AAV6, etc. Furthermore, 5' and 3' ITRs which flank a selected nucleotide sequence in an AAV expression vector need not necessarily be identical or derived from the same AAV serotype or isolate, so long as they function as intended, i. e., to allow for excision and rescue of the sequence of interest from a host cell genome or vector, and to allow integration of the DNA molecule into the recipient cell genome when AAV Rep gene products are present in the cell.

[0034] Particularly preferred are vectors derived from AAV serotypes having tropism for and high transduction efficiencies in cells of the mammalian CNS, particularly neurons. A review and comparison of transduction efficiencies of different serotypes is provided in this patent application. In one preferred example, AAV2 based vectors have been shown to direct long-term expression of transgenes in CNS, preferably transducing neurons. The vectors of the invention are derived from AAV10 and AAV11 serotypes, which have also been shown to transduce cells of the CNS.

[0035] The selected nucleotide sequence is operably linked to control elements that direct the transcription or expression thereof in the subject in vivo. Such control elements can comprise control sequences normally associated with the selected gene.

[0036] Alternatively, heterologous control sequences can be employed. Useful heterologous control sequences generally include those derived from sequences encoding mammalian or viral genes. Examples include, but are not limited to, the phophoglycerate kinase (PKG) promoter, CAG, neuronal promoters, promoter of Dopamine-1 receptor and Dopamine-2 receptor, the SV40 early promoter, mouse mammary tumor virus LTR promoter; adenovirus major late promoter (Ad MLP); a herpes simplex virus (HSV) promoter, a cytomegalovirus (CMV) promoter such as the CMV immediate early promoter region (CMVIE), rous sarcoma virus (RSV) promoter, synthetic promoters, hybrid promoters, and the like. In addition, sequences derived from nonviral genes, such as the murine metallothionein gene, will also find use herein. Such promoter sequences are commercially available from, e. g., Stratagene (San Diego, CA). For purposes of the present description, both heterologous promoters and other control elements, such as CNS-specific and inducible promoters, enhancers and the like, will be of particular use.

[0037] Examples of heterologous promoters include the CMV promoter. Examples of CNS specific promoters include those isolated from the genes of myelin basic protein (MBP), glial fibrillary acid protein (GFAP), and neuron specific enolase (NSE).

[0038] The AAV expression vector which harbors the DNA molecule of interest bounded by AAV ITRs, can be constructed by directly inserting the selected sequence (s) into an AAV genome which has had the major AAV open reading frames ("ORFs") excised therefrom. Other portions of the AAV genome can also be deleted, so long as a sufficient portion of the ITRs remain to allow for replication and packaging functions. Such constructs can be designed using techniques well known in the art. See, e. g. , U. S. Patents Nos. 5,173, 414 and 5,139, 941; International Publications Nos. WO 92/01070 (published 23 January 1992) and WO 93/03769 (published 4 March 1993). Alternatively, AAV ITRs can be excised from the viral genome or from an AAV vector containing the same and fused 5' and 3'of a selected nucleic acid construct that is present in another vector using standard ligation techniques. AAV vectors which contain ITRs have been described in, e. g. , U. S. Patent no. 5,139, 941. In particular, several AAV vectors are described therein which are available from the American Type Culture Collection ("ATCC") under Accession Numbers 53222,53223, 53224,53225 and 53226. Additionally, chimeric genes can be produced synthetically to include AAV ITR sequences arranged 5'and 3'of one or more selected nucleic acid sequences. Preferred codons for expression of the chimeric gene sequence in mammalian CNS cells can be used. The complete chimeric sequence is assembled from overlapping

oligonucleotides prepared by standard methods. In order to produce AAV virions, an AAV expression vector is introduced into a suitable host cell using known techniques, such as by transfection. A number of transfection techniques are generally known in the art. Particularly suitable transfection methods include calcium phosphate coprecipitation, direct microinjection into cultured cells, electroporation, liposome mediated gene transfer, lipid-mediated transduction, and nucleic acid delivery using high-velocity microprojectiles.

[0039] For instance, a particular viral vector, such as the AAV10 or AAV9, comprises, in addition to a nucleic acid sequences of the description, the backbone of AAV vector with ITR derived from AAV-2, the promoter, such as the mouse PGK (phosphoglycerate kinase) gene or the cytomegalovirus/β-actin hybrid promoter (CAG) consisting of the enhancer from the cytomegalovirus immediate gene, the promoter, splice donor and intron from the chicken β-actin gene, the splice acceptor from rabbit β-globin, or any neuronal promoter such as the promoter of Dopamine-1 receptor or Dopamine-2 receptor, or the synapsin promoter, with or without the wild-type or mutant form of woodchuck hepatitis virus post-transcriptional regulatory element (WPRE). The viral vector may comprise in addition, a nucleic acid sequence encoding an antibiotic resistance gene such as the genes of resistance ampicilline (AmpR), kanamycine, hygromycine B, geneticine, blasticidine S or puromycine.

[0040] In a particular embodiment, the vector of the description contains a nucleic acid sequence that encodes the APP protein or APP mutated familiar forms (for example Tottori, Flemish, Arctic, Dutch, Iowa, Iranian, Austrian, German, French, Florida, Indiana or Australian mutations) and in particular APPsl (Swedish and London mutations).

[0041] In another particular embodiment, the vector of the description contains a nucleic acid sequence that encodes the PS1 protein, PS1 M146L, or PS2.

[0042] In another particular embodiment, the vector of the description contains a nucleic acid sequence that encodes the APPsl protein and a nucleic acid sequence that encodes the PS1 protein.

[0043] In another particular embodiment, the vector of the description contains a nucleic acid sequence that encodes the APPsl protein and a nucleic acid sequence that encodes the PS1 protein or a nucleic sequence that encodes the PS2 protein.

[0044] In another particular embodiment, the vector of the description contains a nucleic acid sequence that encodes the APPsl protein, a nucleic acid sequence that encodes the PS1 protein and a nucleic sequence that encodes the PS2 protein.

[0045] In a particular embodiment of the description, the vector of the description is a viral vector, for example the AAV10 or AAV9 vectors which contains a nucleic acid sequence that encodes the APPsl protein and a nucleic acid sequence that encodes the PS1 protein M146L and/or a nucleic sequence that encodes the PS2 protein, the gene AmpR, sequences ITR and the promoter CAG.

[0046] In a particular embodiment, the vector of the description is a viral vector, for example the AAV10 or AAV9 vectors which contains a nucleic acid sequence that encodes the APP protein and a nucleic acid sequence that encodes the PS1 protein spaced by a nucleic acid sequence that encodes a self-cleaving peptide (especially T2A peptide) and the promoter CAG.

Methods of the invention

[0047] A first object of the invention relates to a method for inducing the Alzheimer's disease in a rodent or a non-human primate, said method comprising the administration of at least one vector containing a nucleic acid sequence that encodes the APP protein and the PS1 protein.

[0048] The vector used for inducing the Alzheimer's disease comprises the nucleic acid sequence that encodes the APP protein and the nucleic acid sequence that encodes the PS1 protein.

[0049] In another embodiment, the method for inducing the Alzheimer's disease in a rodent or a non-human primate comprises the administration of a vector containing a nucleic acid sequence that encodes the APPsl protein and a vector containing a nucleic acid sequence that encodes the PS1 protein M146L.

[0050] In a particular embodiment, the method for inducing the Alzheimer's disease in a rodent or a non-human primate comprises the administration of a vector containing a nucleic acid sequence that encodes the APP protein and nucleic acid sequence that encodes the PS1 protein and optionally a vector containing a nucleic acid sequence that encodes the PS2 protein.

[0051] Particularly, the method according to the description is not a method of treatment, in particular a method of treatment of the human or animal body by surgery or therapy.

[0052] Methods of delivery of vectors to neurons and/or astrocytes of the animal of the invention model includes generally any method suitable for delivery vectors to the neurons and/or astrocytes such that at least a portion of cells of a selected synaptically connected cell population is transduced. Vectors may be delivered to any cells of the central nervous system, or both. Generally, the vector is delivered to the cells of the central nervous system, including for example cells of the spinal cord, brainstem (medulla, pons, and midbrain), cerebellum, diencephalon (thalamus, hypothalamus), telencephalon (corpus striatum, cerebral cortex, or, within the cortex, the occipital, temporal, parietal or frontal

lobes), or combinations thereof, or preferably any suitable subpopulation thereof. Further preferred sites for delivery include the ruber nucleus, corpus amygdaloideum, entorhinal cortex and neurons in ventralis lateralis, or to the anterior nuclei of the thalamus.

[0053] In a particular embodiment, vectors of the invention are delivered by stereotactic injections or microinjections directly in the brain and more precisely in the hippocampus.

[0054] To deliver vectors of the description specifically to a particular region and to a particular population of cells of the CNS, vectors may be administered by stereotaxic microinjection. For example, animals have the stereotactic frame base fixed in place (screwed into the skull). The brain with stereotactic frame base (MRIcompatible with fiducial markings) is imaged using high resolution MRI. The MRI images are then transferred to a computer which runs stereotactic software. A series of coronal, sagittal and axial images are used to determine the target (site of AAV vector injection) and trajectory. The software directly translates the trajectory into 3 dimensional coordinates appropriate for the stereotactic frame. Holes are drilled above the entry site and the stereotactic apparatus positioned with the needle implanted at the given depth. The AAV vector is then injected at the target sites. Since the AAV vector integrates into the target cells, rather than producing viral particles, the subsequent spread of the vector is minor, and mainly a function of passive diffusion from the site of injection and of course the desired transsynaptic transport, prior to integration. The degree of diffusion may be controlled by adjusting the ratio of vector to fluid carrier.

[0055] Additional routes of administration may also comprise local application of the vector under direct visualization, e. g., superficial cortical application, or other nonstereotactic application. The vector may be delivered intrathecally, in the ventricules or by intravenous injection.

[0056] Preferably, the method of the invention discloses intracerebral administration through stereotaxic injections. However, other known delivery methods may also be adapted in accordance with the description. For example, for a more widespread distribution of the vector across the CNS, it may be injected into the cerebrospinal fluid, e. g. , by lumbar puncture. To direct the vector to the peripheral nervous system, it may be injected into the spinal cord or into the peripheral ganglia, or the flesh (subcutaneously or intramuscularly) of the body part of interest. In certain situations the vector can be administered via an intravascular approach. For example, the vector can be administered intra-arterially (carotid) in situations where the blood-brain barrier is disturbed or not disturbed. Moreover, for more global delivery, the vector can be administered during the "opening" of the blood-brain barrier achieved by infusion of hypertonic solutions including mannitol.

[0057] Vectors used herein may be formulated in any suitable vehicle for delivery. For instance they may be placed into a pharmaceutically acceptable suspension, solution or emulsion. Suitable mediums include saline and liposomal preparations. More specifically, pharmaceutically acceptable carriers may include sterile aqueous of non-aqueous solutions, suspensions, and emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils such as olive oil, and injectable organic esters such as ethyl oleate. Aqueous carriers include water, alcoholic/aqueous solutions, emulsions or suspensions, including saline and buffered media. Intravenous vehicles include fluid and nutrient replenishers, electrolyte replenishers (such as those based on Ringer's dextrose), and the like.

[0058] Preservatives and other additives may also be present such as, for example, antimicrobials, antioxidants, chelating agents, and inert gases and the like.

[0059] A colloidal dispersion system may also be used for targeted gene delivery. Colloidal dispersion systems include macromolecule complexes, nanocapsules, microspheres, beads, and lipid-based systems including oil-in-water emulsions, micelles, mixed micelles, and liposomes.

[0060] In another embodiment, the method according to the description may further comprise injections of molecules that can help to establish the Alzheimer's disease in a rodent or a non-human primate. For example, the protein ApoE can be injected or overexpressed to the rodent or the non-human primate to promote the process of establishing the disease.

[0061] Thus, the invention may disclose a method for inducing the Alzheimer's disease in a rodent or a non-human primate, said method comprising the administration of at least one vector containing a nucleic acid sequence that encodes the APP protein and/or the PS1 protein or a variant thereof and the protein ApoE.

[0062] In another embodiment, the method for inducing the Alzheimer's disease in a rodent or a non-human primate comprises the administration of a vector comprising the nucleic acid sequence that encodes the APPsl protein and the nucleic acid sequence that encodes the PS1 protein and the protein ApoE.

[0063] In another embodiment, the method for inducing the Alzheimer's disease in a rodent or a non-human primate comprises the administration of a vector containing a nucleic acid sequence that encodes the APP protein and a vector containing a nucleic acid sequence that encodes the PS1 protein and the protein ApoE.

[0064] Particularly, a vector containing a nucleic acid sequence that encodes the protein ApoE may be use in the method according to the description.

[0065] Particularly, a vector containing a nucleic acid sequence that encodes the protein ApoE2 or ApoE3 or ApoE4 may be use in the method according to the description.

[0066] As used herein, the term "protein ApoE" denotes a protein which confers a risk for Alzheimer and cardiovascular

disease. The ApoE gene codes for a protein which is implicated in the cholesterol regulation. There are three relatively common allelic variants of ApoE (accession number: NP_000032.1) known as ApoE2, ApoE3, and ApoE4. The most common variant overall is ApoE3 which is neutral. ApoE2 protect while ApoE4 confers a higher risk for Alzheimer and cardiovascular disease.

[0067] In another aspect, the invention discloses a vector containing a nucleic acid sequence that encodes the APP mutated familiar forms (for example Tottori, Flemish, Arctic, Dutch, Iowa, Iranian, Austrian, German, French, Florida, Indiana or Australian mutations) and in particular APPsl and/or the PS1 protein for use in a method for inducing the Alzheimer's disease in a rodent or a non-human primate.

A rodent or a non-human primate of the invention

[0068] A second object of the invention relates to a rodent or a non-human primate having the Alzheimer's disease, said rodent or non-human primate being obtained by the method according to the invention.

[0069] A rodent or a non-human primate obtained by the method of the description will preferably display increased production of amyloid peptides, hyperphosphorylation of endogenous Tau protein and cognitive deficits, parameters which are characteristics of Alzheimer's disease.

[0070] Thus, in a specific embodiment, said rodent or non-human primate is for use as a model of Alzheimer's disease. The invention further discloses the use of a rodent or a non-human primate having increased production of amyloid peptides, hyperphosphorylation of endogenous Tau protein and cognitive deficits as a model of Alzheimer's disease, said rodent or non-human primate being obtained by the method of the invention.

[0071] The animal obtained by the method of the invention is a rodent or a non-human primate. Particularly, said animal obtained by the method of the description is not a human. Typically, the animal obtained by the method of the description may be a rat, a mouse or a macacus microceb. The animal may be a genetically modified animal, such as a 'knockout' animal in which the function or expression of a gene has been reduced or eliminated.

[0072] Animals of the invention obtained by the method of the description can be easily distinguished from prior art Alzheimer models and offer many advantages (see examples).

[0073] Indeed, contrary to prior art transgenic animals, animals of the invention obtained by the method of the invention can be obtained rapidly e.g. in one month and can be obtained in several animal lines for example in most of the mouse lines. Moreover, said animal obtained by the method of the invention overcomes two major drawbacks of transgenic models: 1) continuous transgenes expression from in utero, 2) limitation of the transgenesis to mice.

[0074] Furthermore, contrary to animal obtained by injection, animals obtained by the method product all neurotoxic metabolites derived from APP (Aβ42 and βCTF), in a continuous manner and in a pathophysiologic level.

Methods of screening of the invention

[0075] Such rodent or a non-human primate model may for instance be of major interest for industrial validation of current and future treatments against this disease.

[0076] Therefore, in a third object, the invention relates to a method of screening a compound for therapeutic use in the treatment of Alzheimer's disease, using the rodent or the non-human primate of the invention.

[0077] The invention also discloses the use of said rodent or a non-human primate for assessing potential side-effects of treatment of Alzheimer's disease. Said treatment may include, for example, administration of therapeutic compounds that act on APP accumulation, as described below.

[0078] The compound to be screened for therapeutic use against Alzheimer's disease may be used for preventing or treating Alzheimer's disease. Such compound may be any kind of compound that may act Alzheimer's disease. It may for instance decrease accumulation of APP and/or decrease accumulation of neurotoxic metabolites derived from APP (Aβ42 and βCTF) for example. The compound to be screened for therapeutic use against Alzheimer's disease should preferably display a low toxicity.

[0079] The screening may for instance include the steps of administering a compound to be screened to the rodent or a non-human primate of the description, waiting for a certain period of time, optionally repeating the administration, measuring the accumulation of APP and/or neurotoxic metabolites, and selecting the compound according to its effect on the accumulation of APP and/or neurotoxic metabolites. For example, if the compound tested allows a decrease of the accumulation of APP and/or neurotoxic metabolites, it could be select as potential therapeutic drug against Alzheimer's disease.

[0080] Alternatively, the rodent or the non-human primate of the invention may also be for use for studying the mechanism of Alzheimer's disease. Another embodiment concerns the use of a rodent or a non-human primate having Alzheimer's disease for studying the mechanism of the disease, said rodent or non-human primate being obtained by the method of the invention. For instance, such a rodent or a non-human primate can be useful for understanding the physiopathology or the molecular mechanism involved in Alzheimer's disease.

[0081] The invention will be further illustrated by the following figures and examples. However, these examples and figures should not be interpreted in any way as limiting the scope of the present invention.

FIGURES:

[0082]

Figure 1. Western blot analysis of transgene expression. (A) Representative Western blots of PS1 M146L, human APP (hAPP) and human + murine APP (total APP: tAPP) in hippocampus homogenates transduced by AAV9 or AAV10 vectors carrying the PS1 M146L (PS1*), APPsl (APP) and/or APPsl + PS1 M146L (APP/PS1*) transgenes. (B) A densitometric analysis of the immunoreactivities to the antibodies shown in panel A confirms effective expression of our transgenes.

Figure 2. Amyloidogenic processing of APP. APP protein is cleaved by the β secretase which leads to the production of soluble fragment sAPPβ and βCTF fragment that remains anchored in the membrane. The βCTF is then cleaved by the PS1 (belonging to the γ secretase complex) allowing production of Aβ42 and Aβ40 peptides.

Figure 3. Simultaneous intracerebral injection of AAV10-APPsl and AAV10-PS1 M146L in 8 weeks old C57BL/6J mice induce amyloid cascade one month after injection. APP is metabolized to (A) βCTF and then (B) Aβ42 peptide. (C) In contrast to APP and βCTF that decreased with PS1 M146L overexpression, Aβ42 production is increased confirming the interest of the simultaneous intracerebral injection of both vectors. (D) In accordance, abnormal phosphorylation on Threonine residue 181 of murine Tau was stimulated by the double injection of AAV coding for APP and PS1 M146L genes. In all cases, AAV10 induced greater production of neurotoxic metabolites.

Figure 4: Simultaneous intracerebral injection of AAV10-APPsl and AAV10-PS1 M146L in 8 weeks old C57BL/6J mice induce amyloid cascade at least up to five months. (A) The amyloidogenic pathway of APP involved in AD leads to the production of two metabolites of the neurotoxic APP peptides, Aβ42 and βCTF into hippocampus. (B) Hippocampal injection of AAV10 vectors encoding the APPsl and PS 1 M146L proteins allowed, within the first month, the induction of a significant production of Aβ42 as well as βCTF. This production was stable with time (analyzed up to 5 months). (C-D) The presence of neurotoxic metabolites of APP did not induce astrocytosis as determined by a stable expression of the Glial acidic fibrillatory protein (GFAP) (C) but led to increased levels of phosphorylated endogenous Tau (D) in mice hippocampus between 3 and 5 post-injection.

Figure 5: Cognitive deficits following simultaneous intracerebral injection of AAV-APPsl and AAV-PS1 M146L. Openfield: (A) Measurement of anxiety levels by analysis of time spent in the periphery relative to the time spent in the center of the apparatus (P/C ratio). The ratio rises when the anxiety of mice rises too. APPsl/PS 1 M146L mice thus appeared hyper-anxious compared to PS1 M146L mice (=0.05). Morris water maze: (B) Both groups, APPsl/PS1 M146L and PS1 M146L mice, had an equivalent learning abilities. This learning was confirmed by the appearance of a spatial bias between learning days 1 and 5. (C) Unlike APPsl/PS1 M146L mice, PS1 M146L mice showed a significant preference for the target quadrant suggesting a long term memory impairment of APPsl/PS1 M146L mice 72 hours after learning session (n = 8 mice per group).

Figure 6: AAV-APP and AAV-PS1 co-injection leads to AD-like production levels of amyloid derivatives. (A) Human APP quantification (6e10 antibody) of hippocampus samples showing a comparison between AAVs injected animals (5 months old, 3 months post-injection, n=3 per group), human controls and AD cases (n=5 per group) and APP/PS1ΔE9 mice (5 months old, n=3). APP levels were normalized to GAPDH. Data are means ± s.e.m. One Way Anova: ***p<0.0001. (B) βCTF comparative analysis by ELISA between human controls and AD cases, AAV co-injected animals and APP/PS1ΔE9 mice at 5, 14 and 16 months old (n = 5, 5, 4, 4, 3, 8, 8 per group respectively). Data are means ± s.e.m. One Way Anova: ***p<0.001. (C) Representation of Aβ40 / Aβ42 ratio for the same groups described in panel (B). Data are means ± s.e.m. One Way Anova: **p<0.01; ***p<0.001.

Figure 7: AAV-APP and AAV-PS1 co-injection allows a hyperphosphorylation of the murine Tau protein from 1 month post-injection. (A) P-Tau (AT270, Thr181) comparative analysis by ELISA between AAV10 injected animals (1 month post-injection, n=3-5 mice per group). (B) GSK-3β comparative analysis by ELISA between AAV10 injected animals (n=3-5 mice per group). One Way Anova: *p<0.05. (C) P-Tau (AT270, Thr181) comparative analysis by ELISA showing significant higher levels in the APP/PS1 group at 3 months post-injection (n=3-5 mice per group). One Way Anova: *p<0.05. (D) Evolution of endogenous Tau hyperphosphorylation over time using four independent experiments with 1 or 3 months old mice (n=17-24 mice per group). Two Way Anova: *p<0.05 (Time effect); **p<0.005 (Group effect).

Figure 8: AAV-APP and AAV-PS1 co-injection causes a neuronal network failure 3 months post-injection. (A) Western-blot analysis of PSD-95 performed from hippocampus samples showing a comparison between PS1 and APP/PS1 mice at 3 months post-injection (n=4 per group). Data are means ± s.e.m and were normalized by GAPDH. t-test, p=0.007. (B) Tonic Glutamatergic Current recorded at a holding potential of +40 mV by whole-cell patch-clamp of CA1 pyramidal neurons.

Figure 9: AAV-APP and AAV-PS1 co-injection leads to a reduction of gabaergic synaptic marker Gad65. (A) Western-blot analysis of Gad65 performed from hippocampus samples showing a comparison between PS1 and APP/PS1 mice at 3 months post-injection (n=4 per group). Data are means ± s.e.m and were normalized by GAPDH. t-test. (B) Western-blot analysis of Gad65 performed from hippocampus samples showing a comparison between human controls and AD cases (n=5 per group). Data are means ± s.e.m and were normalized by GAPDH. t-test.

Table 1: Comparative table of some AAV models of AD.

"AAV models"	Species	Number of viruses	Overexpressed proteins	Peptides production					Memory defects	Behavioral defects
				APP	Aβ42	Aβ40	β-F	Phosphorylated Tau		
AAV-APP. SLA (Jaworski et al.)	Mouse	1	APPsla	Yes	ND	ND	ND	Yes	ND	Yes
AA V-BRI-Aβ42 (Lawlor et al.)	Rat	1	Aβ42	No	Yes	No	No	ND	No	Yes
AAV-BMI-Aβ40 (Lawlor et al.)	Rat	1	Aβ40	No	No	Yes	No	ND	No	Yes
AAV-BRI-Aβ42/AAV-BRI-Aβ40 (Lawlor et al.)	Rat	2	Aβ42 & Aβ40	No	Yes	Yes	No	ND	No	Yes
AAV-APPsw (Lawlor et al.)	Rat	1	APPsw	Yes	No	Yes	ND	ND	No	ND
AAV-Aβ42 (Drummond et al.)	Mouse	1	Aβ42	No	No	No	No	ND	ND	ND
AAV-Aβ40 (Drummond et al.)	Mouse	1	Aβ40	No	No	No	No	ND	ND	ND
AA V-C100 (Drummond et al.)	Mouse	1	β-CTF	No	No	No	Yes	ND	ND	ND
AA V-Tau-P301L (Jaworski et al.)	Mouse	1	Tau	No	No	No	No	Yes	ND	ND
Model of the invention	Mouse	2	APPsl & PS1*	YYes	YYes	NNo	Yes	Yes	Yes	Yes

[0083] Comparative view of some AD models induced by AAV injection. This comparative analysis is based on classical specifications in AD like neurotoxic peptides production and behavioral failures.

Table 2: Comparative table of some transgenic models of AD.

Update of transgenic animal models of AD with a comparison of neurotoxic peptides and cognitive functions onset.						
"Gold standard models »	Overexpressed proteins	Peptides production		Phosphorylated Tau (in months)	Memory defects (in months)	Behavioral defects (in months)
		Aβ42 (in months)	B-CTF (in months)			
PDAPP (Weiss et al.)	APP	8			13	3
Tg2576 (Westerman et al.)	APP	6			6	
TgAPP23 (Wolf et al.)	APP	6		12	3	10
J20 (Palop et al.)	APP	2			6	
TgCRND8 (Nalbantoglu et al.)	APP	6			3	
TgCTF104 (Nalbantoglu et al.)	β-CTF	No	Yes		8	
TgβCTF99/B6 (Lee et al.)	β-CTF	No	4		7	13
BRI-Aβ42A (McGowan et al.)	Aβ42	3				
APPswe/PSldE9 (Kim et al.)	APPsl & PS1	7	Yes	No	8	7
5x FAD (Devi et al.)	APPsl & PS1	1,5			4	
JNPL3 (Lewis et al.)	Tau	No	No	3		
V337M tg (Tanemura et al.)	Tau	No	No	11		11
THY-Tau22 (Schindowski et al.)	Tau	No	No	3	6	6
3x Tg (Oddo et al.)	APPsl, PS1 & Tau	4			6	
Model of the invention	APPsl & PS1*	1	1	3	2,5	2,5

EXAMPLE:

Material & Methods

Tissue collection

[0084] Test mice were anesthetized with ketamine/xylazine and perfused transcardially with 20 ml PBS. One hemisphere was post-fixed for 24h in 4% PFA, cryoprotected in 30% of sucrose in PBS and cut into 40 μm sections using a freezing microtome for immunohistochemical and histological analyses (data not shown). The other half was frozen immediately on dry ice and used for Western blots and ELISAs.

ELISAs and Western blots

[0085] Mice hippocampal tissue was homogenized in a lysis buffer (TBS, NaCl 150 mM, Triton 1%, Phosphatase and Protease inhibitors) and centrifugated 20' at 13000 rpm. Protein levels were normalized by BCA protein assay (Pierce Biotechnology). Extracted Aβ was then measured using the MSD Human Aβ42 Kit. βCTF was measured using the IBL Human βCTF Kit and the P-Tau using the Innogenetics Phospho-Tau 181P Kit. Aliquots of protein were electrophoretically separated using NuPAGE Bis-Tris Gels (Life Technologies). Electrophoresed proteins were then transferred to nitrocellulose membranes using the iBlot 7-Minute Blotting System, blocked in Tris-buffered saline containing 5% non-fat dry milk and subsequently hybridized with vaarious primary antibodies: APP 6E10 (Sigma), APP Cter (Calbiochem) and Presinilin 1 (Millipore). Densitometry quantification of bands was realised with the BioID software.

Behavioral analysis

[0086] *Open field*: Movement in an open field was used to assess whether APP and PS1 injection had an effect on anxiety which may affect memory and learning behaviors. Mice were placed in the center of a square field. The amount of time spent at the periphery along the walls was recorded as measures of anxiety.

[0087] *Morris water maze*: The Morris water maze (MWM) task quantifies mice memory abilities (Morris, 1984). This test was used as a measure of spatial learning, the mouse must learn the location of a hidden platform by referring to visual cues placed around the room. The platform location was kept constant throughout training but the starting point varied between trials. MWM consists of five consecutive learning days (3 trials per day). Seventy-two hours after the last trial of the fifth day a probe trial is realized to quantify long-term memory. In both testing phases, distance traveled in the quadrant containing the platform or target quadrant is quantified. An effective memory storage must therefore be accompanied by the establishment of a spatial bias characterized by a distance travelled in the target quadrant over than 25%.

Results

Example 1: Relevance of the animal model

[0088] To evaluate the relevance of our model, we have performed a comparative study between AAV9 and AAV10 vectors encoding the codon-optimized human APP (APPsl, Swedish-London mutations, promoting the cleavage by β secretase complex) and/or PS1 M146L (M146L) transgenes in mice (Figure 1). Stereotactic injections were performed bilaterally in the hippocampus, an early-affected region in AD.

[0089] These results show that the expression of human APPsl by gene transfer leads to lowly increase the total quantity of APP. Co-express with the PS1 M146L, human APP and βCTF amount decrease due to APP metabolization by secretase complexes. Moreover, AAV10 virus seems to be better to efficiently produce human APP in mice than AAV9 virus.

[0090] AD is characterized by the amyloidogenic pathway of APP metabolism that results from the cleavage of APP by PS1 (Figure 2). Animals injected with AAV vector encoding human PS1 M146L protein only (control animal) or with AAV vectors encoding the APPsl and PS1 M146L were sacrificed at 1 month post-injection for histopathological (data not shown), and biochemical and molecular studies (Figures 3).

[0091] We confirmed by immunohistochemistry our results showed in Figure 1: AAV10 seems to be better than AAV9 to express APP, in particular in CA2 and Subiculum regions of the hippocampus (data not shown). Co-expression of APPsl and PS1 M146L leads to decreased concentration of βCTF as revealed by APP C-ter antibody, or 4G8 antibody staining (data not shown). Expression of PS1 M146L leads to increased metabolism of βCT in Aβ42 peptides as explained in Figure 2.

Example 2: Production of metabolites in the animal model

[0092] APP is cleaved into different metabolites like C-terminal fragment of APP (βCTF) and Aβ42 peptide with characterized neurotoxic properties. We showed that expression of PS1 M146L leads to increased metabolism of βCTF in Aβ42 peptides. Indeed decreased concentration of βCTF is observed in the hippocampus of mice co-injected with AAV10-APPsl and AAV10-PS1 M146L vectors (Figure 3).

[0093] The amount of βCTF showed respectively a 56- and 25-fold increase for APPsl and APPsl/PS1 M146L mice compared to PS1 M146L control mice one month after injection (Figure 3A). Overexpression of human APPsl thus significantly promotes the production of βCTF. βCTF concentration is decreased in APPsl/PS1 M146L mice compared to APPsl mice, demonstrating increased metabolism of βCTF with overexpression of PS1 M146L. βCTF was also detected in cortical structures in the absence of cortical production sites which argues for diffusion of βCTF produced into the hippocampus towards the cortical structures (data not shown). Aβ42 (the main neurotoxic peptide in AD) production is, on the other side, strongly increased in APPsl/PS1 M146L mice.

[0094] A longitudinal study was performed to analyze the kinetics of neurotoxic peptides production in mouse brain (Figure 4). A statistically significant (43 fold) increase of Aβ42 peptides production was observed in mice injected with both AAV10-APPsl and AAV10-PS1 M146L vectors in the hippocampus (p=.002). βCTF production also showed a significant 15-fold increase (p=.0001). In addition, evidence of murine Tau hyperphosphorylation (Threonine residue 181) appeared between 3 and 5 months after injection (p=0.03).

Example 3: Behavioral analysis of the animal model

[0095] At 2.5 months post-injection, a behavioral study was performed in injected animals (Figure 5) for a period of 2.5-3 months. The Openfield test was used to evaluate spontaneous locomotion of mice and behavior response to a new environment. The ratio between time spent in the periphery (noted P, area less anxiogenic) and in the center (noted C) of the open field was significantly increased in APPsl/PS1 M146L mice compared to PS1 M146L mice ($p<0.05$), suggesting an increased level of anxiety in APPsl/PS1 M146L mice.

[0096] During the learning phase of the Morris water maze test, no learning defect was observed in APPsl/PS1 M146L compared to PS1 M146L control mice The two groups had therefore a normal learning profile. During the restitution phase of acquired information (72 hours retention time), a failure to return to platform quadrant previously acquired was observed in APPsl/PS1 M146L mice. The distance traveled by the mouse PS1 M146L in the target quadrant (TQ) was significantly greater than in other quadrants (p=0.01) confirming the presence of a spatial bias. The presence of this spatial bias was not observed for APPsl/PS1 M146L mice (p=ns). So APPsl/PS1 M146L mice traveled less distance in the quadrant previously containing the platform. These results confirm a lack of long-term memory in these mice compared to control mouse PS1 M146L (p=0.02).

[0097] In conclusion, AAV-APPsl and AAV-PS1 M146L injection in wild type mouse leads to rapid (1 month) and stable (evaluated up to 5 months) increased production of amyloid peptides, hyperphosphorylation of endogenous Tau protein and cognitive deficits in mice, parameters which are characteristics of Alzheimer's disease.

[0098] Such models could be useful to analyze deleterious mechanisms induced by amyloid pathway, as well as to evaluate biomarkers or screen therapeutic approaches.

Example 4: Advantages of animal model of the invention from other models

[0099] The generation of AD animal models aims to reproduce symptoms, injuries or causes similar to those observed in the human disease. Many strains of transgenic mice are successful to reproduce these lesions: extracellular deposits of Aβ peptide and intracellular accumulation of Tau protein. However the existing models are imperfect. To identify new therapeutic targets and the effectiveness of treatments in AD, various pharmaceutical companies have developed their own mouse models. Some companies also developed / used different models for provision of services as Contract Research Organizations (CROs).

[0100] These models have specific drawbacks:

- Transgenic models have an important expression of transgenes from the embryonic stages of development which will ultimately lead to the establishment of adaptive mechanisms. In addition, the cost of production is very high. They often imperfectly reproduce the AD phenotype and are difficult to transpose to larger species. Obtain models of AD in large species (rats and primates in particular) would be crucial to develop biomarkers and validate therapeutic approaches in a context as close as possible to the human pathophysiology.
- Models by intracerebral injection of amyloid peptides, truncated or not, are very easy to develop, relatively inexpensive and do not induce adaptive mechanisms. However, they suffer from several drawbacks:in addition to providing a partial model of AD, they do not have all the neurotoxic products generated in AD and in particular βCTF, products

described as highly neurotoxic even at low doses. The administered concentrations of Aβ42 or 25-35 are much higher than those observed in human pathological conditions. These models are therefore particularly suitable for measuring the neuroprotective ability of drugs but have a reduced interest to characterize compounds that modulate the pathological APP metabolism or intracellular changes resulting from the production of neurotoxic metabolites derived from APP.

[0101] In comparison with current transgenic models, the present AAV-APPsl / AAV-PS1 M146L model offers many advantages (see table 2):

- No establishment of breeding colony, but induction of "on-demand model", on standard commercial animals with an expression of toxic metabolites of APP at one month after injection: saving time (at least one year for the establishment of sufficient colony to produce experimental batches) and financial gain (no need to decontaminate strains before implantation nor to keep the breeding continuously).
- Ability to induce amyloid pathology in specific transgenic mouse lines. It could be useful to determine the involvement of new therapeutic targets (for example to understand a hypothetic involvement of the kinase DIRK1A in AD we could induce the amyloid pathology by these constructions in a model of mice over-expressing DIRK1A protein).
- The use of a model by gene transfer overcomes two major drawbacks of transgenic models: 1) continuous transgenes expression from in utero, 2) limitation of the transgenesis to mice. The transfer of this technology in other species (particularly rats & non-human primates) will allow imaging studies, search for biomarkers in cerebrospinal or blood fluids and more advanced cognitive tests.

[0102] As compared to models by injection, our model has many advantages (see table 1):

- Production of all neurotoxic metabolites derived from APP (Aβ42 and βCTF)
- Continuous production of all neurotoxic APP derivatives
- Pathophysiologic production level

[0103] Thus, a mouse model (and/or rat) of Alzheimer's disease by gene transfer would be a powerful tool that would combine the advantages of transgenic animals (complete and stable modeling of the amyloid cascade) without the inconvenience of adaptive mechanisms, and with reduced production costs. Such model could be a major alternative for companies like CROs.

Example 5: Gene transfer leads to APP and cleavage products levels close to humans

[0104] In order to confirm the relevance of this strategy compared to human physiopathology, we performed a comparative study between hippocampus homogenates from 3 months old APP/PS1 mice, human samples (age matched non dementia controls & AD Braak 6 / Thal 5 patients; n= 5/group) and 5 months old APP/PS1ΔE9 commonly used as gold standard.

[0105] An APP decrease was observed in both pathologic groups i.e. AAV-APP/PS1 and AD Braak VI Thal V patients (Figure 6A) in comparison to their respective controls. In contrast to APP/PS1 mice, a significant higher amount of human APP (n=3-5 samples per group,

***p<0.0001) was measured in APP/PS1ΔE9 transgenic mice (Figure 6A) which furthermore increase with age (data not shown). We further evaluated the total APP amount (murine + human forms). Strikingly, there was no significant overproduction of total APP in contrast to APP/PS1ΔE9 mice (data not shown). No APP accumulation over time was measured during at least 12 months post-injection. We then evaluated catabolites derived from the amyloidogenic pathway in the hippocampus. First of all, βCTF levels were similar between APP/PS 1 mice and AD patients. Significant higher levels were measured in APP/PS1ΔE9 mice confirming age-dependent APP and βCTF accumulation in these animals (Figure 6B; n=3-8 samples per group,
***p<0.0001). Thus, ELISA revealed APP/PS1 Aβ42 amounts comprised between controls and AD patients. Higher levels were observed in transgenic mice. In addition, no significant difference appeared between Aβ40 levels between human samples and AAV mice unlike with transgenic samples. We finally calculated the Aβ40/Aβ42 ratio and similar values were obtained between AD patients and APP/PS1 group. Interestingly it appeared that 16 months old is not sufficient to obtain the same ratio in APP/PS1ΔE9 mice (Figure 6C). Altogether, our data strongly suggest that amyloid processing due to AAV injection is closer humans that transgenic APP/PS1dE9 mice.

Example 6: APP/PS1 co-injection triggers a hyperphosphorylation of the endogenous Tau protein

[0106] Given the evidence that human APP is processed following the amyloidogenic pathway we examined the potential impact on the hyperphosphorylation of the murine Tau. We detected an increase in the APP/PS1 group (n=4) compared to the APP (n=4) and PS1 (n=4) groups (Figure 7A). We also measured a higher amount of GSK-3β, key kinase implicated in the Tau phosphorylation (Figure 7B). ELISA assay realized on 3 months old APP/PS1 mice showed thereby a significant hyperphosphorylation of Tau (Figure 7C; n=3-4 mice per group, *$p<0.05$). To ensure that there is indeed a trend concerning the phosphorylation state of Tau, we performed a comparative analysis between the APP and APP/PS1 group normalized on PS1 group (Figure 7D). Data cumulated from four different experiments with 1 or 3 months old mice were used (n=17-24 mice per group) and showed a significant effect of group (**$p<0.005$) and time (*$p<0.05$) suggesting an exacerbation of tau phosphorylation over time.

Example 7: APP/PS1 mice present a failure of the neuronal network

[0107] It is well known that synaptic dysfunctions appear as an early event in AD (Scheff et al., 2007). Some synaptic markers like PSD-95 have been showed as reduced in AD patients (Proctor et al., 2010). We evaluated PSD-95 levels in the hippocampus of our model at 3 months post-injection. A significant decrease appeared in the APP/PS1 group compared to PS1 group (Figure 8A; n=4 per group, p=0.007). Whole-cell patch-clamp recording of CA1 pyramidal cells was performed and Tonic Glutamatergic Current was recorded. Significant increase appeared in the APP/PS1 group meaning that Glutamate activate preferentially extrasynaptic NMDARs in this group (Figure 8B; n=11-19 per group).

Example 8: APP/PS1 mice present an altered GABA pathway

[0108] Increasing evidences appeared these past few years about a decreased GABAergic signaling in AD patients (Gang et al., 2009; Xue et al., 2014; Tiwari et al., 2012). Using a 11.7 Tesla MRI, Magnetic Resonance Spectroscopy analysis was performed on PS1 and APP/PS1 mice at 3 months post-injection (n=6 per group). The region of interest was selected in both hippocampus of each mouse brain (data not shown). Results for the APP/PS1 were normalized to the PS1 values. APP/PS1 mice have significantly lower concentrations of Glutamine (Gln; p=0.017), GABA (p=0.018) and NAA (p=0.04) than PS1 mice indicating a decreased neuronal health and particularly a decreased GABA signaling pathway. No differences were obtained between both groups in the levels of Glu, tNAA, Ins and tChol (data not shown). Glutamine is the precursor of Glutamate which is itself the precursor of the GABA neurotransmitter. To explain why we observed a decrease of Glutamine and GABA but not of Glutamate, we looked for the Gad65 expression. Gad65 is an enzyme which catalyzes the decarboxylation of Glutamate to GABA for neurotransmission. It appeared decreased in the APP/PS1 mice at 3 months after injection compared to PS1 mice (Figure 9A; n=4 mice per groups, p=0.03). Interestingly, a decrease of Gad65 was also shown in human patients compared to control patients (Figure 9B; n=5 patients per groups, p=0.1).

Example 9: injection of the CAG-APP-T2A-PS1 construct

[0109] We generate an AAV vector coding for a fusion protein containing APP and PS 1 protein spaced by a self-cleaving peptide (T2A peptide). Mice injected with CAG-APP-T2A-PS1 construction present production of neurotoxic metabolites of APP (βCTF, Aβ38/40/42) close to human amounts. Hyperphosphorylation of murine TAU protein is also observable. These cerebral changes lead to behavioral defects in Morris water maze.

Conclusion:

[0110] The inventors describe here the development of an alternative AAV-based mouse model with two major objectives: create a relevant model closer to human physiopathology and mimic the early stages of AD. This model was obtained by co-injection, in the hippocampus of wild-type mice, of two AAV vectors coding the human Amyloid Protein Precursor (APPsl) and the human Presinilin 1 (PS1M146L). Our strategy allows a stable expression of transgenes without significant APP overexpression. This leads to βAPP production and its neurotoxic catabolites such as sAPPβ, βCTF and Aβ42 as soon as one month post-injection and stable during at least 12 months without classical late symptoms appearance such as senile plaque, inflammation or atrophy. Otherwise, they measured very close amounts of APP, βCTF and Aβ peptides compared to human homogenates and unlike what we can find in APP/PS1ΔE9 mice. Interestingly, only co-injection triggered hyperphosphorylation of the murine Tau protein resulting from an increase of GSK-3β levels. Finally, significant behavior impairments appeared from 3 months post-injection in association with an alteration of synaptic functions especially a decrease of PSD-95 associated with synaptic defects such as extrasynaptic NMDAR activity and an alteration in the GABAergic pathway.

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[0111] Throughout this application, various references describe the state of the art to which this invention pertains.

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Leu Ile Tyr Thr Pro Phe Thr Glu Asp Thr Glu Thr Val Gly Gln Arg
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Leu Ile Tyr Thr Pro Phe Thr Glu Asp Thr Glu Thr Val Gly Gln Arg
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Phe Ser Phe Ile Tyr Leu Gly Glu Val Phe Lys Thr Tyr Asn Val Ala
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        195                 200                 205

Gly Met Ile Ser Ile His Trp Lys Gly Pro Leu Arg Leu Gln Gln Ala
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Tyr Leu Ile Met Ile Ser Ala Leu Met Ala Leu Val Phe Ile Lys Tyr
225                 230                 235                 240

Leu Pro Glu Trp Thr Ala Trp Leu Ile Leu Ala Val Ile Ser Val Tyr
                245                 250                 255

Asp Leu Val Ala Val Leu Cys Pro Lys Gly Pro Leu Arg Met Leu Val
            260                 265                 270

Glu Thr Ala Gln Glu Arg Asn Glu Thr Leu Phe Pro Ala Leu Ile Tyr
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Ser Ser Thr Met Val Trp Leu Val Asn Met Ala Glu Gly Asp Pro Glu
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Thr Glu Lys Asn Gly Gln Leu Ile Tyr Thr Pro Phe Thr Glu Asp Thr
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145                 150                 155                 160

Lys Tyr Arg Cys Tyr Lys Phe Ile His Gly Trp Leu Ile Met Ser Ser
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Leu Met Leu Leu Phe Leu Phe Thr Tyr Ile Tyr Leu Gly Glu Val Leu
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Leu Val Leu Gln Gln Ala Tyr Leu Ile Met Ile Ser Ala Leu Met Ala
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Leu Val Phe Ile Lys Tyr Leu Pro Glu Trp Ser Ala Trp Val Ile Leu
                245                 250                 255

Gly Ala Ile Ser Val Tyr Asp Leu Val Ala Val Leu Cys Pro Lys Gly
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Pro Leu Arg Met Leu Val Glu Thr Ala Gln Glu Arg Asn Glu Pro Phe
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Val Arg Pro Phe Met Asp Thr Leu Ala Ser His Gln Leu Tyr Ile
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Claims

1. A method for inducing the Alzheimer's disease in a rodent or a non-human primate, said method comprising the administration of at least one vector containing a nucleic acid sequence that encodes the APP protein and the PS1 protein, wherein the vector is an adeno-associated virus (AAV) vector 9 or 10.

2. A method for inducing the Alzheimer's disease in a rodent or a non-human primate, said method consisting in the administration of a vector containing a nucleic acid sequence that encodes the APP protein and a vector containing a nucleic acid sequence that encodes the PS1 protein, wherein the vector is an adeno-associated virus (AAV) vector 9 or 10.

3. The method according to claims **1** or **2**, wherein the vector is delivered by stereotactic injections or microinjections directly in the brain.

4. A rodent or a non-human primate having Alzheimer's disease obtained by the method according to any one of claims **1** to **3**.

5. Use of the rodent or non-human primate according to claim **4**, as a model of Alzheimer's disease.

6. A method of screening a compound for therapeutic use in the treatment of Alzheimer's disease using a rodent or a non-human primate of claim **4.**

7. A method of assessing side effects of a treatment of Alzheimer's disease using a rodent or a non-human primate of claim **4.**

Patentansprüche

1. Verfahren zum Induzieren der Alzheimer-Krankheit bei einem Nagetier oder einem nicht-menschlichen Primaten, wobei das Verfahren das Verabreichen von mindestens einem Vektor umfasst, der eine Nukleinsäuresequenz enthält, die das APP-Protein und das PS1-Protein codiert, wobei der Vektor ein Adeno-assoziiertes Virus- (AAV) Vektor 9 oder 10 ist.

2. Verfahren zum Induzieren der Alzheimer-Krankheit bei einem Nagetier oder einem nicht-menschlichen Primaten, wobei das Verfahren in der Verabreichung eines Vektors, der eine Nukleinsäuresequenz enthält, die das APP-Protein codiert, und eines Vektors, der eine Nukleinsäuresequenz enthält, die das PS1-Protein codiert, besteht, wobei der Vektor ein Adeno-assoziiertes Virus- (AAV) Vektor 9 oder 10 ist.

3. Verfahren nach den Ansprüchen **1** oder **2**, wobei der Vektor durch stereotaktische Injektionen oder Mikroinjektionen direkt in das Gehirn appliziert wird.

4. Nagetier oder nicht-menschlicher Primat, das/der die Alzheimer-Erkrankung aufweist, die über das Verfahren nach einem der Ansprüche **1** bis **3** erhalten wurde.

5. Verwendung des Nagetiers oder nicht-menschlichen Primaten nach Anspruch **4** als ein Modell der Alzheimer-Krankheit.

6. Verfahren zum Screenen einer Verbindung zur therapeutischen Verwendung in der Behandlung von Alzheimer-Krankheit unter Verwendung eines Nagetiers oder eines nicht-menschlichen Primaten nach Anspruch **4.**

7. Verfahren zum Beurteilen von Nebenwirkungen einer Behandlung der Alzheimer-Krankheit unter Verwendung eines Nagetiers oder eines nicht-menschlichen Primaten nach Anspruch **4.**

Revendications

1. Une méthode pour induire la maladie d'Alzheimer chez un rongeur ou un primate non-humain, ladite méthode comprenant l'administration d'au moins un vecteur contenant une séquence d'acide nucléique qui encode la protéine APP et la protéine PS1, dans laquelle le vecteur est un virus adénoassocié (AAV) 9 ou 10.

2. Une méthode pour induire la maladie d'Alzheimer chez un rongeur ou un primate non-humain, ladite méthode consistant en l'administration d'un vecteur contenant une séquence d'acide nucléique qui encode la protéine APP et un vecteur contenant une séquence d'acide nucléique qui encode la protéine PS1, dans laquelle le vecteur est un virus adénoassocié (AAV) 9 ou 10.

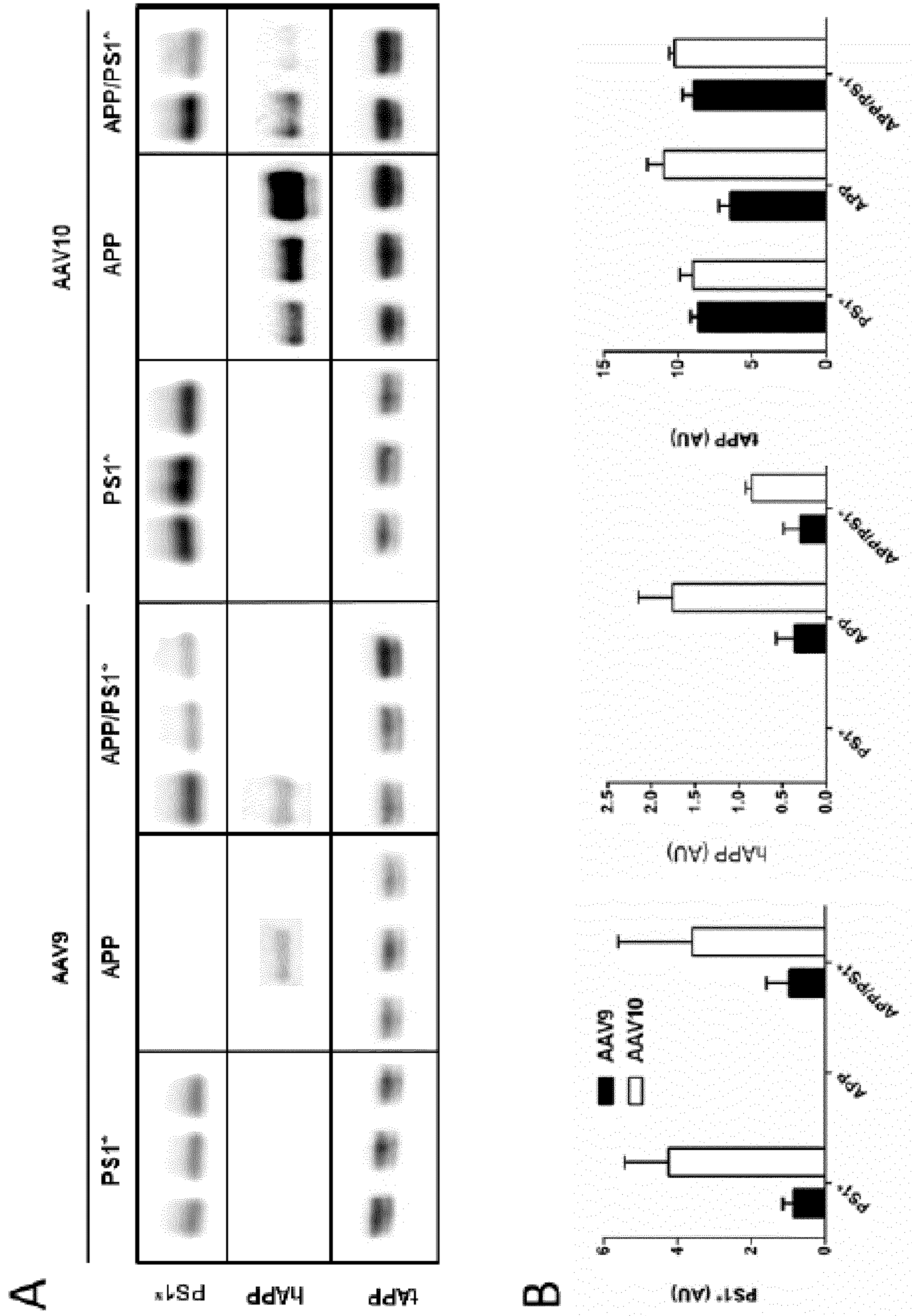
3. La méthode selon la revendication **1** ou **2**, dans laquelle le vecteur est administré par injections stéréotaxiques ou par microinjections directement dans le cerveau.

4. Un rongeur ou un primate non-humain ayant la maladie d'Alzheimer, obtenu par la méthode selon l'une quelconque des revendications **1** à **3**.

5. Utilisation du rongeur ou du primate non-humain selon la revendication **4**, en tant que modèle de la maladie d'Alzheimer.

6. Une méthode de criblage d'un composé à usage thérapeutique dans le traitement de la maladie d'Alzheimer, utilisant le rongeur ou le primate non-humain selon la revendication **4**.

7. Une méthode d'évaluation des effets secondaires d'un traitement de la maladie d'Alzheimer, utilisant le rongeur ou le primate non-humain selon la revendication **4**.



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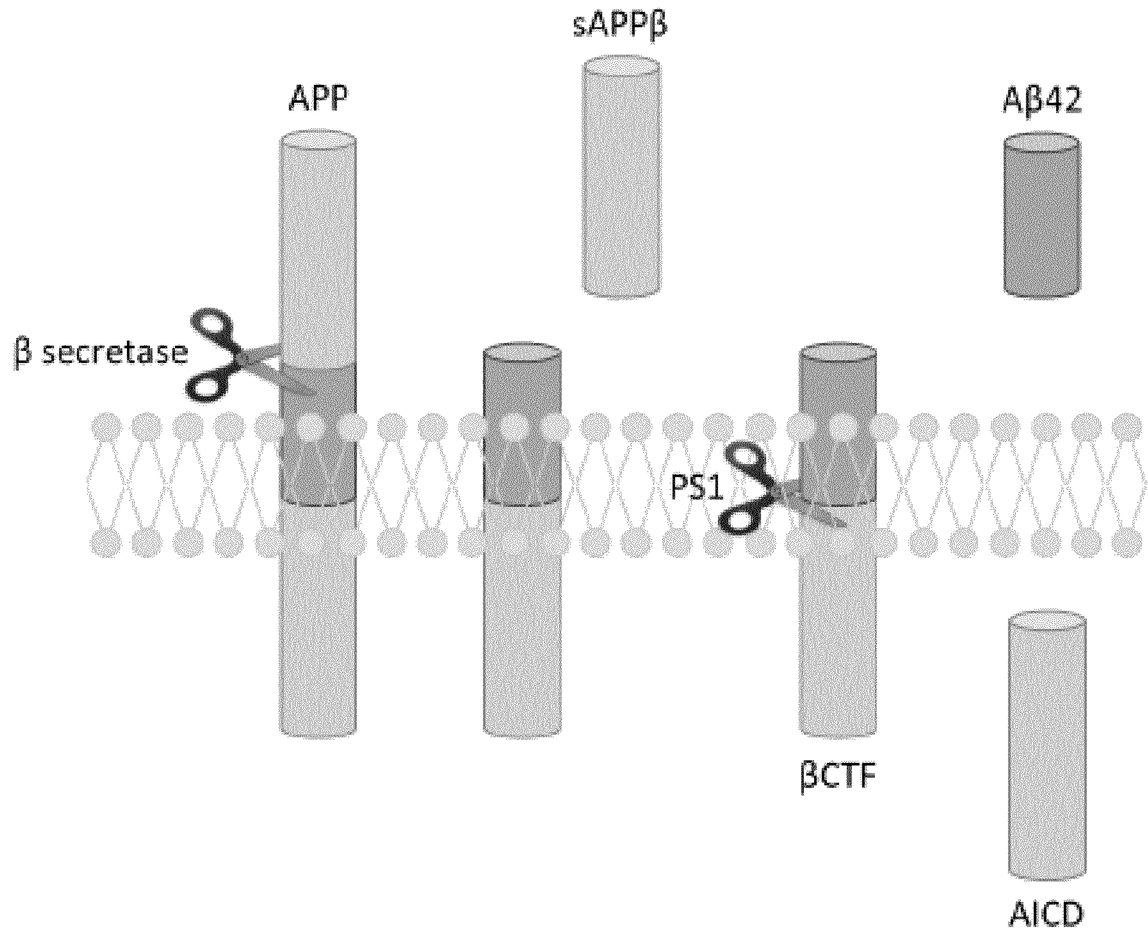

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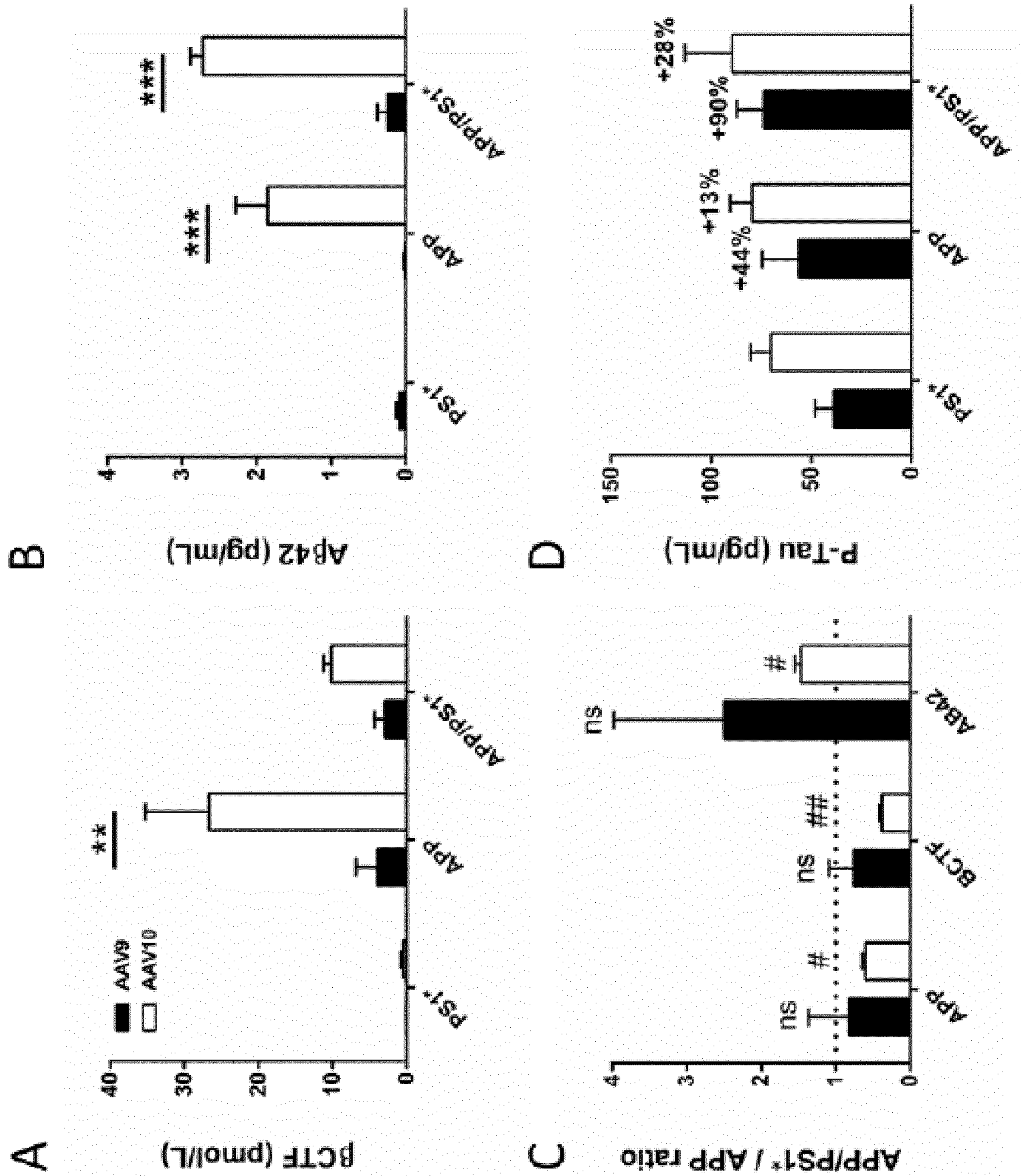

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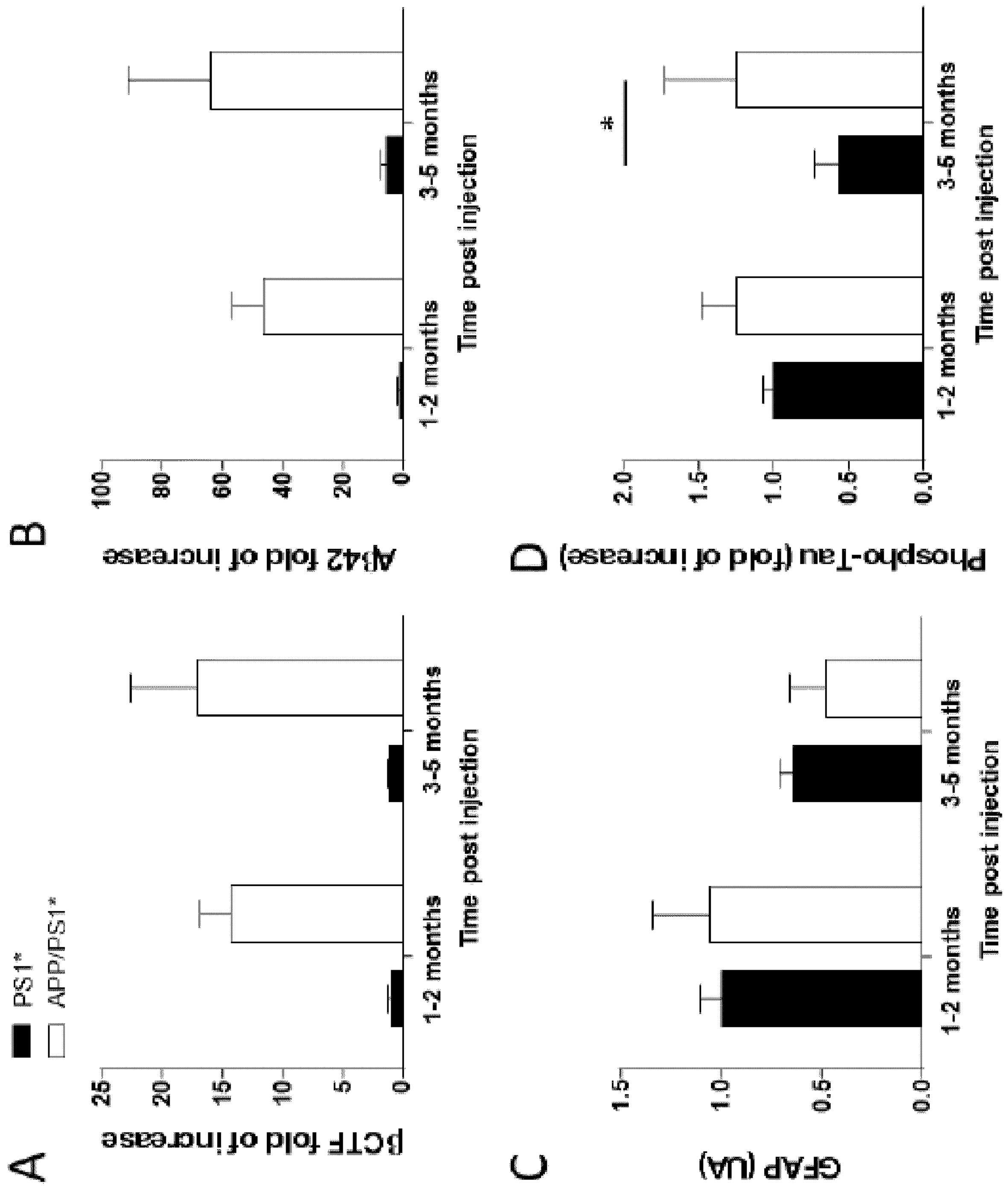

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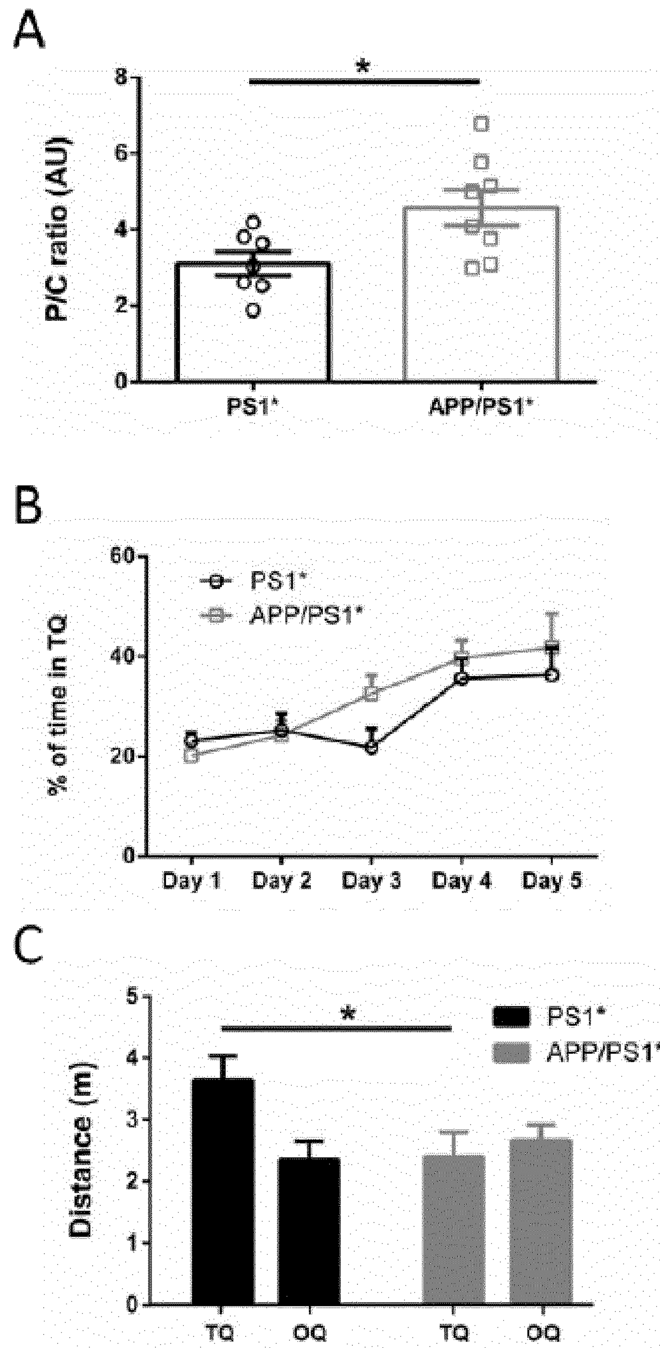

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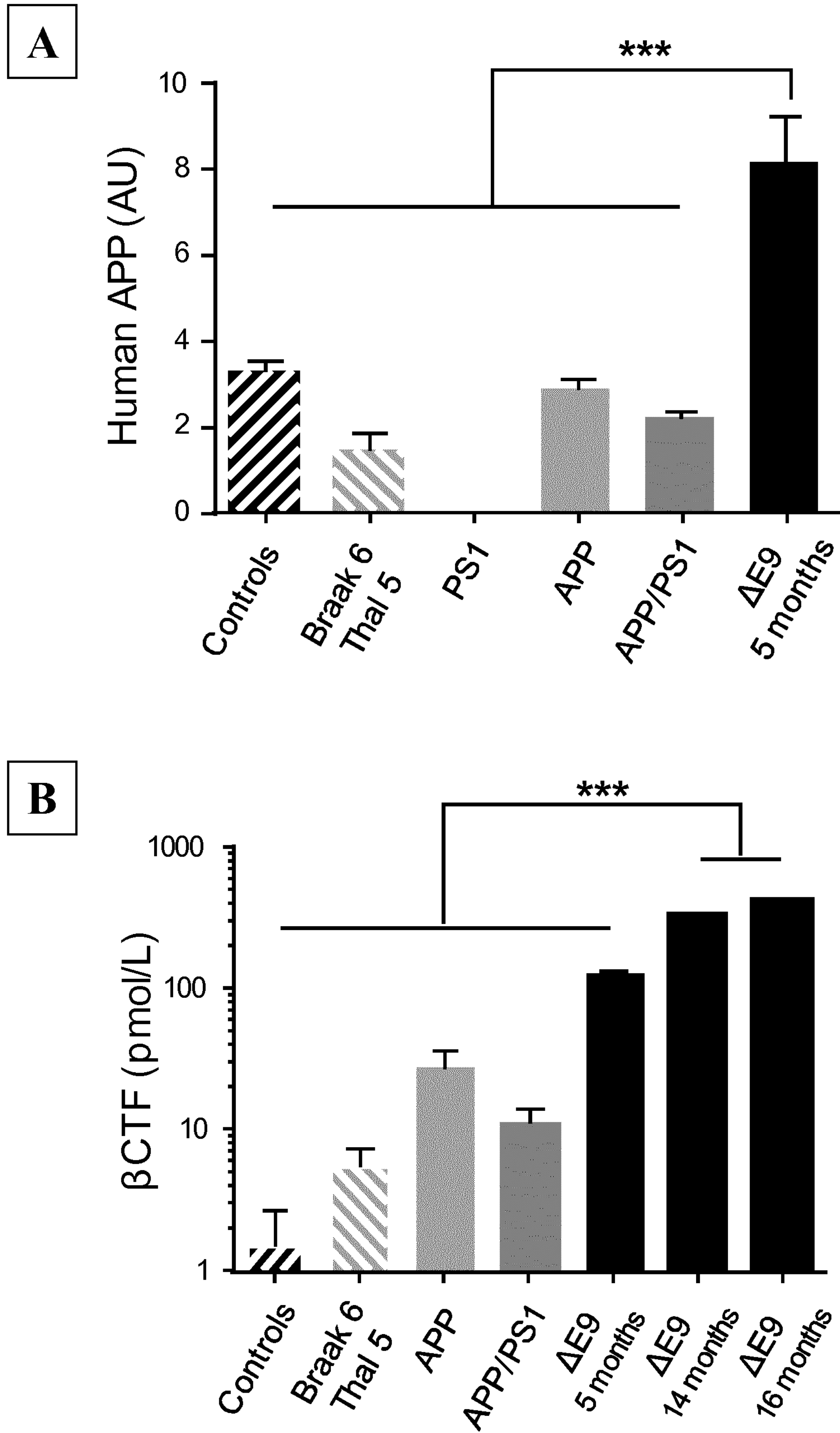
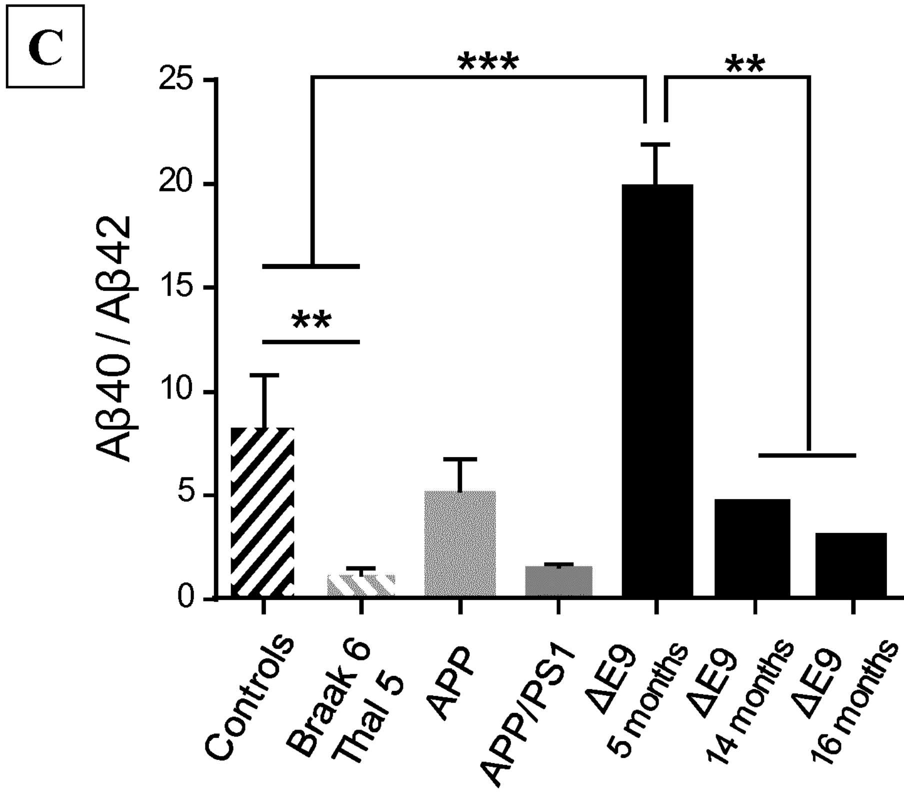


Figure 6 A and B



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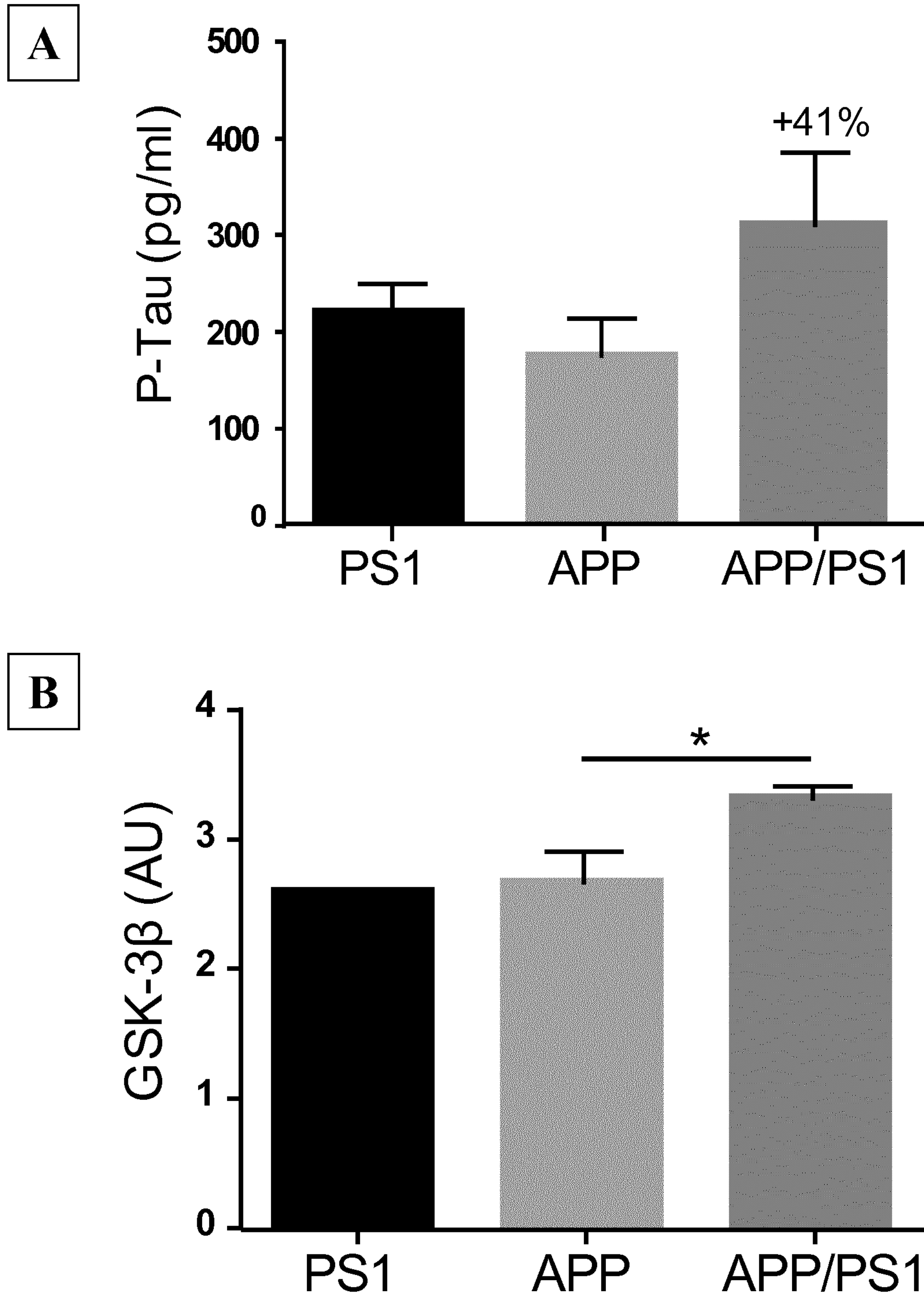

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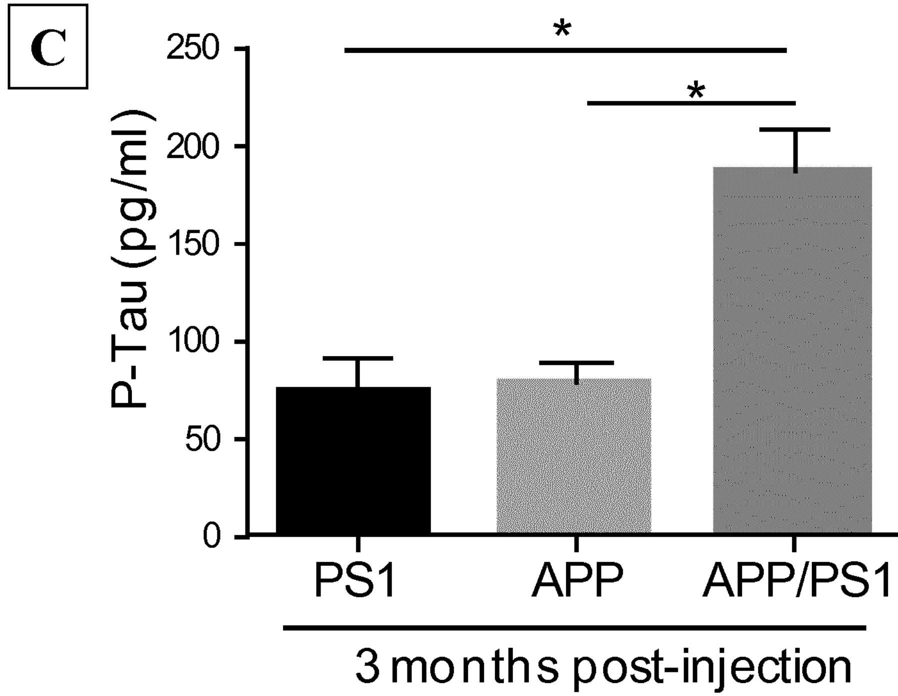

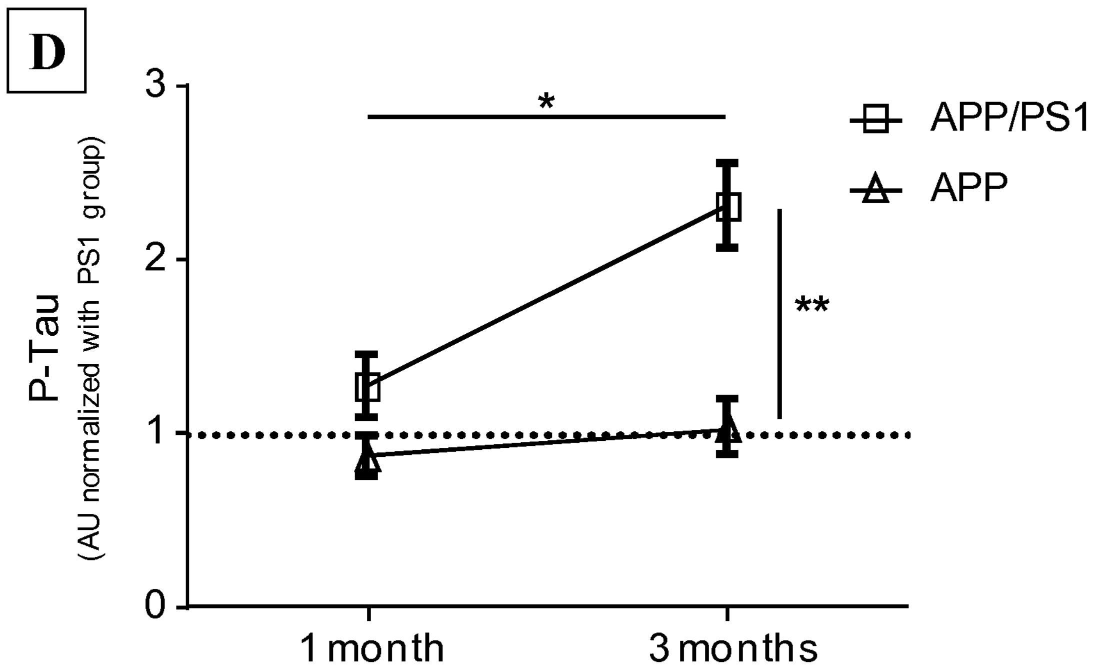

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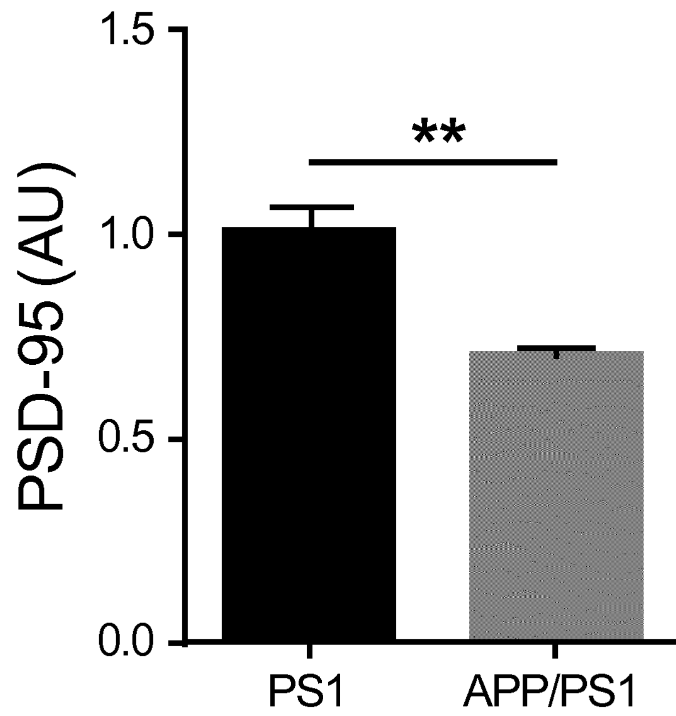

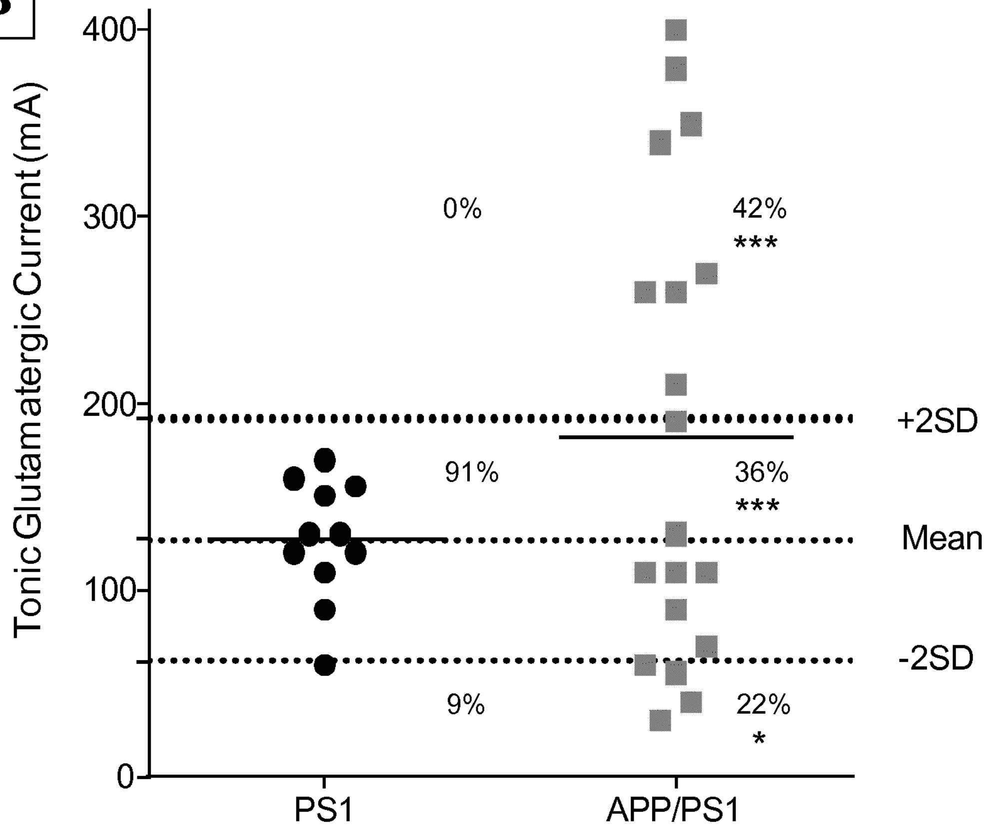

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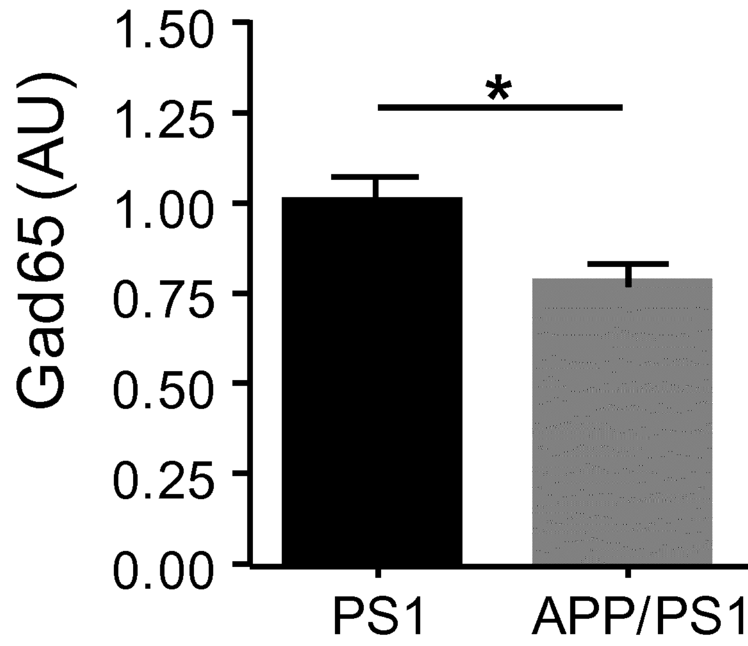

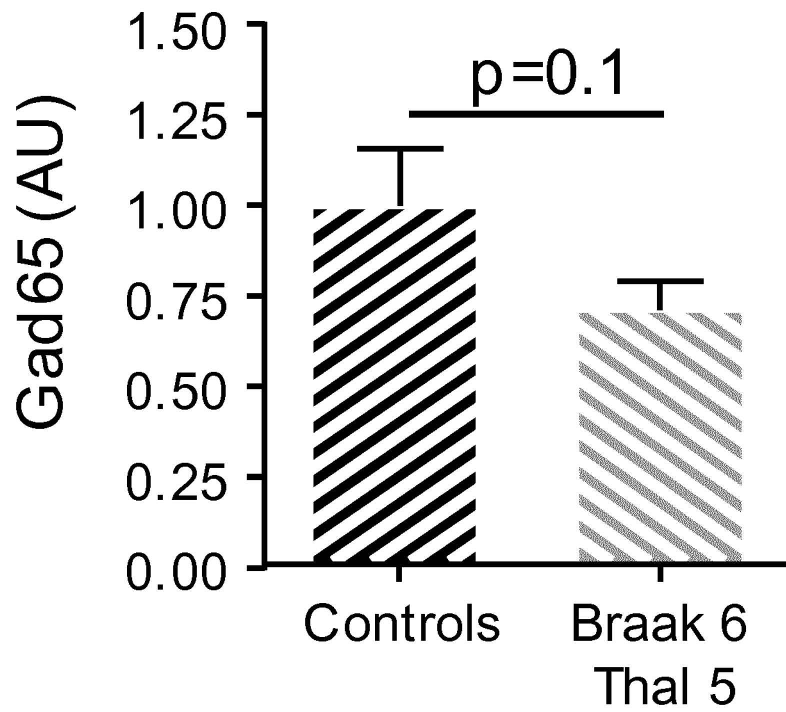

Figure 9 A and B

REFERENCES CITED IN THE DESCRIPTION

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