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(54) **PHOSPHORYLATION ON THE THR-248 AND/OR THR-250 RESIDUES OF TRANSCRIPTION FACTOR E2F4 AS A THERAPEUTIC TARGET IN PATHOLOGICAL PROCESSES ASSOCIATED WITH SOMATIC POLYPLOIDY**

PHOSPHORYLIERUNG AUF DEN THR-248 UND/ODER THR-250-RESTEN DES TRANSKRIPTIONSFAKTORS E2F4 ALS THERAPEUTISCHES ZEILMOLEKÜL BEI PATHOLOGISCHEN PROZESSEN IM ZUSAMMENHANG MIT SOMATISCHER POLYPLOIDIE

PHOSPHORYLATION DANS LES RÉSIDUS THR-248 ET/OU THR-250 DU FACTEUR DE TRANSCRIPTION E2F4 EN TANT QUE CIBLE THÉRAPEUTIQUE DANS DES PROCESSUS PATHOLOGIQUES QUI DÉBOUCHENT SUR UNE POLYPLOÏDE SOMATIQUE

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Description

Field of the Art

[0001] The present invention belongs to the pharmaceutical sector, relating specifically to molecular target identification for developing therapeutic tools.

Prior State of the Art

[0002] The association existing between cell cycle reactivation in postmitotic cells with subsequent *de novo* DNA synthesis and various pathological processes affecting both neurons (neurodegeneration, ischemia, etc.) and myocytes (hypertrophic cardiomyopathy, vascular pathologies associated with hypertension and aging) is known. In many cases, cell cycle reactivation does not involve cell division but rather is part of an endoreduplication mechanism (Ullah *et al.,* 2009) which translates into the generation of somatic polyploidy (polyploidy that only affects certain cell types and is not passed on from generation to generation). Perhaps one example of a pathology associated with somatic polyploidy is Alzheimer's disease (AD). It is known that in this disease neurons reactivate the cell cycle before degenerating (Yang *et al.,* 2003), increasing nuclear DNA content (Arendt *et al.,* 2010). These neurons are likely to experience morphological and functional modifications compromising their survival (Frade and Lopez-Sanchez, 2010). In fact, it has been described that hyperploid neurons are those that predominantly degenerate in the brain of patients with AD (Arendt *et al.,* 2010). Cardiac muscle tissue also contains a percentage of polyploid myocytes, the proportion of which may be altered in pathological situations (Yabe and Abe, 1980; Vliegen *et al.,* 1995). Vascular smooth muscle can also suffer impairments associated with polyploidy (McCrann *et al.* 2008). For these reasons, knowledge of the molecular base involved in endoreduplication will facilitate the design of therapeutic tools that prevent pathologies associated with somatic polyploidization. Therapeutic tools aiming to prevent somatic endoreduplication associated with human pathologies have not been developed until now, most likely because it is a very recent field of research in which new concepts are starting to emerge.

[0003] US20080139517A1 proposes administering one or more agents capable of inhibiting neuronal cell cycle progression either in an early cell cycle phase or by reducing mitogenic stimulation in age associated memory impairment (AAMI), mild cognitive impairment (MCI), AD, cerebrovascular dementia and other retrogenic neurodegenerative conditions. However, said patent document assumes that the degenerative process is associated with conventional cell cycle progression and not endoreduplication. Furthermore, this patent document does not extend the spectrum to other nervous system and heart diseases in which polyploidy-generating cell cycle reactivation has been or may be described.

[0004] It is indicated in Morillo *et al.,* 2010, that the endoreduplication process in neurons leading to neuronal tetraploidy occurs naturally during embryonic development, giving rise to specific neuron populations that acquire a larger size, longer dendrites, and differential innervation regions in their target tissue (Morillo *et al.,* 2010). Endoreduplication in these neurons is known to occur as a response to nerve growth factor NGF-mediated activation of neurotrophins receptor p75 ($p75^{NTR}$). These neurons duplicate their DNA and remain in a G2-like state due to the effect of neurotrophin BDNF which acts through its TrkB receptor preventing G2/M transition. Therefore, neuronal tetraploidization is known to take place during NGF-mediated nervous system development through $p75^{NTR}$, inducing the activity of transcription factor E2F1, to re-enter the cell cycle. Those tetraploid neurons that do not receive sufficient BDNF signal try to perform mitosis followed by apoptotic death. In the brain of Alzheimer's patients, the presence of $p75^{NTR}$ and NGF in the affected regions is known. This suggests that the hyperploidy observed in the affected neurons may be caused by the same mechanism that generates tetraploid neurons during nervous system development. Reduced TrkB levels observed in advanced stages of the disease could facilitate neuronal death (see the development of this model in Frade and Lopez-Sanchez, 2010) .

[0005] Deschênes *et al.* 2004 makes reference to the mechanisms for regulating human intestinal epithelial cell proliferation and differentiation and indicates possible phosphorylation of transcription factor E2F4 by $p38^{MAPK}$. However, this document concludes that there is currently a need to investigate which residues of transcription factor E2F4 would be phosphorylated by $p38^{MAPK}$ as part of the mechanisms for regulating human intestinal epithelial cell proliferation and differentiation.

[0006] It has been disclosed that an inhibitor of $p38^{MAPK}$, SB 239063, produces a maximum reduction of infarct size and neurological deficits in both moderate and severe stroke (Barone et al. 2001). In addition it has been reported that $p38^{MAPK}$ signaling pathway may mediate streptozotocin-induced neurotoxic effects (Sidhart et al. 2011). In relation to Alzheimer's disease Munoz et al. 2010 indicated that $p38^{MAPK}$ could play more than one role in Alzheimer's disease pathophysiology and Kitazawa et al. 2011 reported that inhibition of IL-1 signaling reduces the activity of $p38^{MAPK}$ and also reduces phosphorylated tau levels.

[0007] None of these documents identifies candidate molecules as therapeutic targets for inhibiting pathological polyploidization. Therefore, there is currently a need to prevent endoreduplication causing pathological polyploidization in

postmitotic cells as a therapeutic method by means of identifying new therapeutic targets.

Brief Description of the Invention

[0008] The present invention relates to an inhibitory agent of the phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, for use in the prevention and/or treatment of a pathology associated with somatic polyploidy wherein the inhibitory agent is
a mutant form of transcription factor E2F4 with SEQ ID No: 1 substituted on Thr248 and/or Thr250 residues with an amino acid that cannot be phosphorylated by $p38^{MAPK}$ other than glutamate or aspartate or
a form of E2F4 from species other than human with mutations on conserved Thr residues at positions found within a conserved sequence corresponding to Thr248 and/or Thr250 of the sequence of human E2F4, said mutations consisting of a substitution of the conserved Thr residue by a residue that cannot be phosphorylated by $p38^{MAPK}$ other than glutamate or aspartate,
and wherein said pathology associated with somatic polyploidy is a neurodegenerative disease.

[0009] It is dislosed the use of an inhibitory agent for inhibiting phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, as a therapeutic target in the prevention and/or treatment of a pathology associated with somatic polyploidy.

Detailed Description of the Invention

[0010] According to the present invention, the inhibitory agent of the phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, for use in the prevention and/or treatment of a pathology associated with somatic polyploidy wherein said pathology associated with somatic polyploidy is a neurodegenerative disease, is a mutant form of transcription factor E2F4, the amino acid sequence of which is identified as SEQ ID No: 1 (human). Said mutant form of transcription factor E2F4 with SEQ ID No: 1 is substituted in Thr248 and/or Thr250 residues with an amino acid that cannot be phosphorylated by $p38^{MAPK}$, other than glutamate or aspartate. Said amino acid that cannot be phosphorylated is more preferably alanine.

[0011] It is disclosed herein that the inhibitory agent of the phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, for use in the prevention and/or treatment of a pathology associated with somatic polyploidy, is characterized in that it is an E2F4 fragment comprised in SEQ ID No: 1, with identical capacity for interfering with phosphorylation of endogenous E2F4 by $p38^{MAPK}$.

[0012] In addition, according to the present invention, the inhibitory agent of the phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, for use in the prevention and/or treatment of a pathology associated with somatic polyploidy wherein said pathology associated with somatic polyploidy is a neurodegenerative disease, is characterized in that it is a form of E2F4 from species other than human with mutations on conserved Thr residues at positions found within a conserved sequence corresponding to Thr248 and/or Thr250 of the sequence of human E2F4, said mutations consisting of a substitution of the conserved Thr residue by a residue that cannot be phosphorylated by $p38^{MAPK}$ other than glutamate or aspartate. Said form of E2F4 from species other than human is preferably selected from SEQ ID No 2 (chicken) and SEQ ID No 3 (mouse) (see Figure 1).

[0013] It is also disclosed herein, the inhibitory agent of the phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, for use in the prevention and/or treatment of a pathology associated with somatic polyploidy, is characterized in that it is a synthetic molecule mimicking the mutant form of transcription factor E2F4 of SEQ ID No: 1, substituted with alanine on Thr248 and/or Thr250 residues.

[0014] On the other hand, the present invention relates to the inhibitory agent of the phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, for use in the prevention and/or treatment of a pathology associated with somatic polyploidy, wherein said pathology associated with somatic polyploidy is a neurodegenerative disease, characterized in that said somatic polyploidy occurs as a result of endoreduplication in postmitotic cells. Said postmitotic cells are preferably neurons and/or myocytes.

[0015] The disclosure also relates to the inhibitory agent of the phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, for use in the prevention and/or treatment of a pathology associated with somatic polyploidy, characterized in that said pathology associated with somatic polyploidy is selected from the following group: neurodegenerative disease, ischemia, hypertrophic cardiomyopathy, vascular pathology associated with hypertension and aging. The pathology associated with somatic polyploidy according to the invention is a neurodegenerative disease. Said neurodegenerative disease is even more preferably Alzheimer's disease.

[0016] In another preferred embodiment of the present invention, the inhibitory agent is associated with another cell membrane-permeable peptide facilitating the incorporation thereof into the cell, or the inhibitory agent is comprised in the form of DNA in a vector capable of infecting neurons and/or myocytes, preferably suitable for gene therapy, said vector is more preferably a viral vector, and said viral vector is even more preferably a lentivirus.

[0017] Our laboratory has unveiled the mechanism used by NGF/$p75^{NTR}$ to induce cell cycle reactivation in neurons of chicken during embryonic development, an effect which generates endoreduplication and neuronal tetraploidy (Morillo et *al.,* 2010). Said mechanism is based on the activation of Ser/Thr kinase $p38^{MAPK}$ in the nucleus of affected cells (Figure 2), and subsequent phosphorylation on threonine residues of transcription factor E2F4 (Figure 3). Any other signaling pathway that activates $p38^{MAPK}$ in postmitotic cells could result in hyperploidization using transcription factor E2F4. In chicken, there are only two residues that can be phosphorylated by $p38^{MAPK}$, i.e., threonine residues Thr261 and Thr263 (Figure 1). The use of NetPhosK 1.0 software predicts that these threonine residues are immersed in a domain conserved with human and mouse E2F4 proteins (Figure 1). In the case of human E2F4 protein, the threonine residue that can be phosphorylated by $p38^{MAPK}$, as predicted by NetPhosk 1.0 software, is threonine residue Thr248 (the consensus site for phosphorylation by $p38^{MAPK}$ must have a consecutive Pro residue, a TP sequence, located after said threonine). Human Thr 250 residue has also been considered to be protected even though it lacks a consecutive Pro residue. The reason is its degree of conservation with mouse Thr251 threonine residue and chicken Thr263 threonine residue, both with a consecutive Pro residue and predicted by NetPhosK 1.0 software as threonine residues that can be phosphorylated by $p38^{MAPK}$.

[0018] Phosphorylation of Thr261/Thr263 residues of E2F4 is crucial for cell cycle reactivation induced by NGF through $p75^{NTR}$ in chick embryo retinal cells in neuronal differentiation process (Figure 4). Such cell cycle reactivation leads to neuronal tetraploidy (Morillo *et al.,* 2010). We have observed that the use of a constitutively active form of chicken E2F4, in which Thr261 and Thr263 residues have been substituted with Glu (a positively charged amino acid mimicking the phosphorylated state of Thr) is capable of mimicking the effect of NGF on retinal neurons (Figure 4A, Figure 4B). It has also been demonstrated that the use of a negative dominant form of chicken E2F4 (Thr261Ala/Thr263Ala) preventing phosphorylation thereof by $p38^{MAPK}$ is capable of inhibiting the effect of NGF on the cell cycle in neurogenic retinal cultures (Figure 4C, Figure 4D). Therefore, it is foreseeable that the expression of this mutant form Thr261Ala/Thr263Ala (or the human form Thr248Ala/Thr250Ala) in affected neurons or myocytes associated with the pathologies described above could inhibit the endoreduplication process and the subsequent hyperploidization, which could prevent, or at least slow down, disease progression. It is disclosed herein the use of said mutant forms of E2F4 for preventing hyperploidization and the associated pathological effects in various diseases affecting postmitotic cells (neurons and muscle cells).

[0019] Therefore, the present disclosure demonstrates that phosphorylation on conserved homologous Thr residues of Thr248 and Thr250 of human E2F4 is crucial for inducing endoreduplication in retinal neurons.

[0020] It is also disclosed any method for specifically inhibiting phosphorylation on Thr248 and/or Thr250 residues of human transcription factor E2F4 (hereinafter phosphoE2F4). The inhibition of said phosphorylation would hinder the capacity of E2F4 for inducing DNA synthesis in postmitotic cells, which has clear therapeutic benefits.

[0021] The present dislosure also relates to any method for inhibiting $p38^{MAPK}$/phosphoE2F4 signaling, preferably by means of a mutant form of E2F4 in which the Thr 248 residue and/or Thr250 residue has/have been substituted with an Ala residue, as performed in our laboratory with chicken E2F4.

[0022] Alternatively, the present disclosure also relates to any other method for inhibiting $p38^{MAPK}$/phosphoE2F4 signaling, such as for example:

- substitution of Thr248 and/or Thr250 residues with other amino acids that cannot be phosphorylated,
- use of an E2F4 fragment with identical capacity for interfering with the phosphorylation of endogenous E2F4,
- use of forms of E2F4 from other species with mutations on conserved Thr residues,
- use of synthetic molecules mimicking the mutated form of E2F4, etc.

[0023] The present disclosure also relates to any means for specifically transferring the aforementioned mutated forms of E2F4 into affected cells, such as for example, by means of suitable vectors, peptides that can go through the cell membrane, etc.

[0024] The disclosure involves the following phases:

1) Generating the blocking molecule which blocks phosphorylation of human transcription factor E2F4 in target cells
The molecule chosen for blocking phosphorylation on Thr248 and/or Thr250 residues of human E2F4 (whether it is the gene coding sequence for human E2F4 or E2F4 from another species, the peptide sequence of human E2F4 or E2F4 from another species, the partial gene coding sequence for human E2F4 or E2F4 from another species, the partial peptide sequence of human E2F4 or E2F4 from another species, or another molecule mimicking the region or regions of interaction between E2F4 and $p38^{MAPK}$ capable of blocking phosphorylation on Thr248 and/or Thr250 residues of human E2F4) will be generated by chemical synthesis or by means of cloning the cDNA sequence in a plasmid that can generate suitable vectors for gene therapy.
In this last case, the coding sequence must first be amplified with a heat stable enzyme with proof-reading capacity from cDNA derived from mRNA previously obtained from a cell line or from a tissue of human origin. To clone the

sequence, primers in which restriction sites that are compatible with the polylinker of the vector chosen for cloning have been included, are used. Said vector is chosen based on the method used in Example 4 for introducing the chosen sequence into the target cells. Once the sequence is cloned, a standard site-directed mutagenesis process leading to the specific modification of ACT codon encoding Thr248 and/or Thr250 residues is performed in order to transform said codon into a codon specific for any amino acid except Glu or Asp. The plasmid thus generated is co-transfected into a suitable cell line capable of packaging the vector of interest.

2) Expressing the blocking molecule which blocks phosphorylation of human transcription factor E2F4 in target cells In those cells in which the $p38^{MAPK}$-E2F4 signaling pathway is active, $p38^{MAPK}$ is expected to be inhibited upon binding to the excess molecules mimicking the mutated form of E2F4, capable of interacting with $p38^{MAPK}$ but incapable of being phosphorylated. The endoreduplication process in said cells is therefore blocked. The blocking molecules can be expressed by the same target cells if they are transferred in the form of DNA (using suitable vectors such as lentivirus, for example). Alternatively, the blocking molecules can be transferred by means of peptides capable of going through the cell membrane with greater or less target cell-type specificity.

[0025] Throughout the description and claims, the word "comprises" and variants thereof do not intend to exclude other technical features, additives, components or steps. For persons skilled in the art, other objects, advantages and features of the invention will be inferred in part from the description and in part from the practice of the invention. The following drawings and examples are provided by way of illustration and they are not meant to limit the present invention.

Description of the Drawings

[0026] Figure 1 shows the structure, functional domains and sequence conservation of transcription factor E2F4. The drawing illustrates the comparison between amino acid sequences of human transcription factor E2F4 (*H. sapiens*), mouse (*M. musculus*) transcription factor E2F4, chicken (*G. gallus*) transcription factor E2F4, frog *Xenopus laevis* (*X. laevis*) transcription factor E2F4 and zebrafish (*D. rerio*) transcription factor E2F4. The different known functional domains including the DNA-binding (DB) region, the dimerization (DIM) domain, the marked box (MB) and the transactivation (TA) domain are also indicated. The region including Thr248 and Thr250 residues of the human sequence conserved in other species (indicated by small rectangles) is also indicated: Thr249 and Thr251 residues in the mouse sequence, Thr261 and Thr263 residues in the chicken sequence, Thr228 residue in frog and Thr217 residue in zebrafish. This region is referred to as the regulator domain (RD). Amino acids completely conserved in the regulator domain are indicated with a dot.

[0027] Figure 2 shows that nuclear $p38^{MAPK}$ activation in response to NGF is necessary for cycle reactivation in chick embryo retinal cell neurogenic cultures in E6. These cells respond to NGF by inducing cell cycle reactivation that leads to somatic tetraploidy (endoreduplication) (Morillo *et al.,* 2010). A. Western blot with anti-active $p38^{MAPK}$ ($P\text{-}p38^{MAPK}$) and anti-$p38^{MAPK}$ in nuclear extracts of the mentioned neurogenic cultures treated for the indicated time with 100 ng/ml NGF. The normalized ratios between $P\text{-}p38^{MAPK}$ and $p38^{MAPK}$ levels are indicated at the bottom. B. Immunohistochemical staining with anti- active $p38^{MAPK}$ antibodies ($P\text{-}p38^{MAPK}$) in the mentioned neurogenic cultures treated with 100 ng/ml NGF for 20 minutes. The nuclei were labeled with bisbenzimide (Bisb.). Note the signal increase in the nucleus of cells treated with NGF. C. Luciferase assay in extracts of chick embryo retinal cell neurogenic cultures E6 transfected with a plasmid expressing luciferase under the control of *cMyc* gene promoter, known for its response to E2F during G1/S transition, and another plasmid with the constitutive expression of β-galactosidase. The luciferase/β-galactosidase ratio values are depicted as "luciferase activity". Treatment with 100 ng/ml NGF entails cMyc promoter activation, indicating cell cycle reactivation. This effect is blocked with selective $p38^{MAPK}$ inhibitor SB203580 (used at 5 μM). D. Incorporation of BrdU to indicate entry into S phase in chick embryo retinal cell neurogenic cultures E6. Treatment with 100 ng/ml NGF entails an increase in the proportion of cells in S phase, an effect which is blocked by selective $p38^{MAPK}$ inhibitor SB203580 (used at 5 μM), but not by selective JNK inhibitor, SP600125 (used at 7 μM). *p<0.05; ***p<0.005 (Student's t-test)

[0028] Figure 3 shows NGF-promoted phosphorylation on threonine residues of E2F4 in chick embryo retinal cell neurogenic cultures in E6. The top part shows a Western blot carried out with anti-phosphoThr antibodies (αp-Thr) in extracts immunoprecipitated with anti-E2F4 antibodies originating from the indicated cultures treated with different combinations of 100 ng/ml NGF and selective inhibitor SB203580 (used at 5 μM). The bottom part shows a Western blot carried out with anti-E2F4 antibodies in the same extracts without immunoprecipitation (INPUT). The presence of NGF can be seen to involve an increase in phosphorylation on threonine residues, while the presence of $p38^{MAPK}$ inhibitor inhibits such phosphorylation.

[0029] Figure 4 shows that phosphorylation on Thr261/Thr263 residues of E2F4 is capable of inducing cycle reactivation in chick embryo retinal cell neurogenic cultures in E6. A. Luciferase activity analyzed as described in Figure 2C. The expression of the constitutively active form of E2F4 (E2F4-CA) characterized by Thr261Glu/Thr263Glu substitutions induces cMyc promoter activity, an effect that can be observed even in the presence of selective $p38^{MAPK}$ inhibitor

SB203580 (used at 5 μM). B. The incorporation of BrdU increases significantly in cells transfected with the constitutively active form of E2F4 (E2F4-CA), an effect that can be observed even in the presence of selective $p38^{MAPK}$ inhibitor SB203580 (used at 5 μM). Based on the results shown in panels A and B, it is deduced that $p38^{MAPK}$ acts exclusively through Thr261/Thr263 residues. C. Luciferase activity analyzed as described in Figure 2C. The expression of the negative dominant form of E2F4 (E2F4-ND) characterized by Thr261Ala/Thr263Ala substitutions prevents the effect of 100 ng/ml NGF on cMyc promoter activity. D. The expression of the negative dominant form of E2F4 (E2F4-ND) prevents the effect of 100 ng/ml NGF on the incorporation of BrdU in retinal neurogenic cultures.

[0030] Figure 5 shows the diagram of the method for cloning E2F4 coding sequence into a plasmid that allows generating a suitable vector for gene therapy (lentivirus, etc.), for example. The mRNA obtained from human tissue or cells is converted into cDNA using reverse transcriptase. The human E2F4 coding sequence is depicted as a gray rectangle in which the position of the codon encoding Thr 248 residue is indicated. This codon is flanked by two specific restriction sites (C and D). Two primers are designed based on the sequence of the ends of the coding region with a specific restriction site at the 5' ends (A and B) thereof. These targets also appear in the polylinker of the expression vector and are used for cloning the E2F4 coding sequence into said vector. P: promoter responsible for the transcription of E2F4 protein. pol: polyadenylation sequence used for introducing a poly(A) tail in the mRNA generated by the vector.

[0031] Figure 6 shows the diagram of the E2F4 coding sequence mutagenesis process. A pair of external primers flanking restriction sites C and D (external arrows) and another overlapping pair of internal primers including in the sequence thereof the mutagenized codon of Thr248 (internal arrows) are designed. Two PCR amplification reactions are performed with DNA polymerase Pfu and the reaction products are denatured together. After renaturing the DNA, the situation indicated in the diagram is obtained, among other possibilities. Elongation with DNA polymerase Pfu creates DNA double helices with the sequences of the external primers at the ends thereof. These sequences are exponentially amplified with said primers resulting in DNA fragments with Thr248 residue mutagenized to Ala, flanked by restriction sites C and D. The sequence containing the mutation can be sub-cloned into the expression vector using restriction sites C and D for that purpose.

References

[0032]

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Examples

[0033] The following specific examples provided in this patent document serve to illustrate the nature of the present invention. These examples are included merely for illustrative purposes and must not be interpreted as limiting the invention herein claimed. The examples described below therefore illustrate the invention without limiting the field of application thereof.

Example 1- Cloning human E2F4 coding sequence

[0034] Human E2F4 coding sequence (positions 64-1305 of the sequence with NCBI accession number: NM_001950) (SEQ ID No 4) is cloned into a plasmid that can generate suitable vectors for gene therapy (lentiviral vectors, for example). The coding sequence must be previously amplified with DNA polymerase enzyme Pfu from cDNA derived from mRNA previously obtained from a cell line or from a tissue of human origin. To clone the sequence, primers including EcoRV and PacI restriction sites (underlined in the sequences indicated at the end of this paragraph) that are compatible with the polylinker of lentiviral expression vector are used (see a simple diagram of said vector in Figure 5, the EcoRV site would correspond to A and the PacI site would correspond to B in said diagram). Examples of these oligonucleotides are as follows:

SEQ ID No 5: 5' oligo: 5'-CAACAGATATCATGGCGGAGGCCGGGCCACA-3'
SEQ ID No 6: 3' oligo: 5'-CCATTAATTAAGGGTCCCAGCCACACAGGGC-3'

[0035] The first one corresponds to nucleotides in positions 64-83 and the second one is complementary to nucleotides in positions 1319-1338 of the human E2F4 sequence.

[0036] The amplicon thus obtained is cloned into pGEM-Teasy vector (Promega) which does not have EcoRV or PacI restriction sites, in which site-directed mutagenesis described in Section 2 will be performed.

Example 2- Mutating Thr248 residue (Thr250 residue can be mutated by means of a similar method once the Thr248Ala mutation is generated)

[0037] Once the human E2F4 sequence is cloned into the pGEM-Teasy vector, oligonucleotides are designed in the region comprised between positions 731-754 of human E2F4 coding sequence, corresponding to SEQ ID No 4.

[0038] These oligonucleotides include ACT codon encoding Thr248 residue (in positions 742-744 of human E2F4 coding sequence) that is mutated as Ala specific codon (GCT sequence). Examples of these oligonucleotides are:

SEQ ID No 7: 5'mutated oligo: 5'-TCAGCTCGCTCCCACTGCTG-3' (positions 735-754).
SEQ ID No 8: 3'mutated oligo: 5'-CAGTGGGAGCGAGCTGAGGA-3' (positions 732-751).

[0039] These oligonucleotides (containing the underlined mutation) will be used as primers of two independent reactions indicated in Figure 6. Another pair of primers flanking enzyme BspEI restriction sites (indicated as C and D in Figure 6) is designed for these reactions. The cDNA sequence encoding human E2F4 include two BspEI sites in positions 374-379 and 979-984 with TCCGGA sequence. Examples of these primers are:

SEQ ID No 9: 5' non-mutated oligo: 5'-AAGGTGTGGGTGCAGCAGAG-3' (position 352-371)
SEQ ID No 10: 3' non-mutated oligo: 5'-GGTCTGCCTTGATGGGCTCA-3' (position 1005-1025)

[0040] Two PCR amplification reactions are subsequently performed with DNA polymerase Pfu as indicated in the diagram of Figure 6 (5' non-mutated oligo with 3'mutated oligo and 5'mutated oligo with 3' non-mutated oligo), and the reaction products are denatured together. After renaturing the DNA, the situation indicated in the diagram of Figure 6 is obtained, among other possibilities. Elongation of these hybrids with DNA polymerase Pfu creates DNA double helices that can be amplified with external primers (5' non-mutated oligo and 3' non-mutated oligo; see Figure 6). DNA fragments with Thr248 residue mutagenized to Ala, flanked by restriction sites C and D (see Figure 6), are therefore obtained. The sequence containing the mutation can then be sub-cloned into pGEM-Teasy plasmid generated in point 1, using restriction sites C and D (BspEI) for that purpose. After sequencing the modified clones, a clone in which the sequence has been incorporated in the suitable orientation is selected.

Example 3- Generating vectors for therapy that can infect the nervous system

[0041] pGEM-Teasy plasmid with the mutated human E2F4 coding sequence (T248A) is cleaved with EcoRV and

PacI enzymes to release said sequence and is sub-cloned into the polylinker of the lentiviral expression vector pSMPUW-Hygro (Cell Biolabs, Inc.) containing the EcoRV and PacI sites. The vector thus generated is co-transfected into a suitable cell line capable of packaging the vector of interest.

Example 4- Expressing the mutated form of E2F4 in target cells

[0042] In those neurons or myocytes in which the $p38^{MAPK}$-E2F4 signaling pathway is active, $p38^{MAPK}$ is expected to be inhibited upon binding to an excess of mutated E2F4 molecules, similarly to that observed in neurons treated with NGF in the differentiation process. The endoreduplication process in said cells is thus blocked. Given that phosphorylation on Thr248 residue of E2F4 does not take place in other cell functions with the exception of endoreduplication, its presence in other cells should not have side effects.

SEQUENCE LISTING

[0043]

<110> CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS

<120> PHOSPHORYLATION ON THR-248 AND/OR THR-250 RESIDUES OF TRANSCRIPTION FACTOR E2F4 AS A THERAPEUTIC TARGET IN PATHOLOGICAL PROCESSES ASSOCIATED WITH SOMATIC POLYPLOIDY

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        35                  40                  45
Thr Leu Ala Val Arg Gln Lys Arg Arg Ile Tyr Asp Ile Thr Asn Val
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Trp Lys Gly Val Gly Pro Gly Cys Asn Thr Arg Glu Ile Ala Asp Lys
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Ile Cys Arg Cys Phe Ala Gly Asp Thr Leu Leu Ala Ile Arg Ala Pro
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Ser Gly Thr Ser Leu Glu Val Pro Ile Pro Glu Gly Leu Asn Gly Gln
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Lys Lys Tyr Gln Ile His Leu Lys Ser Val Ser Gly Pro Ile Glu Val
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Leu Leu Val Asn Lys Glu Ala Trp Ser Ser Pro Pro Val Ala Val Pro
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Val Pro Pro Pro Glu Asp Leu Leu Gln Ser Pro Ser Ala Val Ser Thr
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Pro Pro Pro Leu Pro Lys Pro Ala Leu Ala Gln Ser Gln Glu Ala Ser
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Glu Val Gln Gly Met Ala Gly Pro Ala Ala Glu Ile Thr Val Ser Gly
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Gly Pro Gly Thr Asp Ser Lys Asp Ser Gly Glu Leu Ser Ser Leu Pro
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Val Pro Pro Pro Asp Asp Leu Leu Gln Ser Pro Pro Ala Val Ser Thr
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Claims

1. An inhibitory agent of the phosphorylation on Thr248 and/or Thr250 residues of transcription factor E2F4 by $p38^{MAPK}$, for use in the prevention and/or treatment of a pathology associated with somatic polyploidy wherein the inhibitory agent is
a mutant form of transcription factor E2F4 with SEQ ID No: 1 substituted on Thr248 and/or Thr250 residues with an amino acid that cannot be phosphorylated by $p38^{MAPK}$ other than glutamate or aspartate or
a form of E2F4 from species other than human with mutations on conserved Thr residues at positions found within a conserved sequence corresponding to Thr248 and/or Thr250 of the sequence of human E2F4, said mutations consisting of a substitution of the conserved Thr residue by a residue that cannot be phosphorylated by $p38^{MAPK}$ other than glutamate or aspartate,
and wherein said pathology associated with somatic polyploidy is a neurodegenerative disease.

2. The inhibitory agent for use according to claim 1, **characterized in that** said amino acid that cannot be phosphorylated is alanine.

3. The inhibitory agent for use according to claim 1, **characterized in that** said form of E2F4 from another species is selected from SEQ ID No 2 and/or SEQ ID No 3.

4. The inhibitory agent for use according to claims 1 to 3, **characterized in that** said somatic polyploidy occurs as a result of endoreduplication in postmitotic cells.

5. The inhibitory agent for use according to claim 4, **characterized in that** said postmitotic cells are neurons.

6. The inhibitory agent for use according to claims 1 to 5, **characterized in that** said neurodegenerative disease is Alzheimer's disease.

7. The inhibitory agent for use according to claim 1, **characterized in that** said inhibitory agent is associated with a a cell membrane-permeable peptide facilitating the incorporation thereof into the cell.

8. The inhibitory agent for use according to claim 1, **characterized in that** said inhibitory agent is comprised in the form of DNA and is comprised in a vector capable of infecting neurons and/or myocytes.

9. The inhibitory agent for use according to claim 1, **characterized in that** said inhibitory agent is expressed by a target cell after said inhibitory agent is transferred to the cell in the form of DNA using a suitable vector.

10. The inhibitory agent for use according to claim 8 wherein the vector is a viral vector.

11. The inhibitory agent for use according to any of claims 9 or 10 wherein the vector is a lentivirus.

Patentansprüche

1. Mittel zum Hemmen der Phosphorylierung bei Thr248- und/oder Thr250-Resten des Transkriptionsfaktors E2F4 durch $p38^{MAPK}$, zu Verwendung zur Verhinderung und/oder Behandlung einer Pathologie, die mit somatischer Polyploidie verbunden ist, wobei das Mittel zum Hemmen Folgendes ist
eine mutante Form des Transkriptionsfaktors E2F4 mit SEQ ID No: 1, die an Thr248- und/oder Thr250-Resten mit einer Aminosäure substituiert ist, die durch $p38^{MAPK}$, mit Ausnahme von Glutamat oder Aspartat, nicht phosphoryliert werden kann, oder
eine Form von E2F4 von Spezies, bei denen es sich nicht um menschliche handelt, mit Mutationen an konservierten Thr-Resten an Positionen, die innerhalb einer konservierten Sequenz anzutreffen sind, die Thr248- und/oder Thr250 der Sequenz von menschlichem E2F4 entspricht, wobei die Mutationen aus einer Substitution der konservierten Thr-Reste durch einen Rest besteht, der durch $p38^{MAPK}$, mit Ausnahme von Glutamat oder Aspartat, nicht phosphoryliert werden kann,
und wobei die Pathologie, die mit somatischer Polyploidie verbunden ist, eine neurodegenerative Krankheit ist.

2. Mittel zum Hemmen zur Verwendung nach Anspruch 1, **dadurch gekennzeichnet, dass** die Aminosäure, die nicht phosphoryliert werden kann, Alanin ist.

3. Mittel zum Hemmen zur Verwendung nach Anspruch 1, **dadurch gekennzeichnet, dass** die Form von E2F4 von einer anderen Spezies unter SEQ ID No: 2 und/oder SEQ ID No: 3 ausgewählt wird.

4. Mittel zum Hemmen zur Verwendung nach den Ansprüchen 1 bis 3, **dadurch gekennzeichnet, dass** die somatische Polyploidie als Folge von Endoreduplikation in postmitotischen Zellen stattfindet.

5. Mittel zum Hemmen zur Verwendung nach Anspruch 4, **dadurch gekennzeichnet, dass** die postmitotischen Zellen Nervenzellen sind.

6. Mittel zum Hemmen zur Verwendung nach Anspruch 1 bis 5, **dadurch gekennzeichnet, dass** die neurodegenerative Krankheit Alzheimer-Krankheit ist.

7. Mittel zum Hemmen zur Verwendung nach Anspruch 1, **dadurch gekennzeichnet, dass** das Mittel zum Hemmen mit einem Zellmembran-durchlässigen Peptid verbunden ist, das das Integrieren davon in die Zelle ermöglicht.

8. Mittel zum Hemmen zur Verwendung nach Anspruch 1, **dadurch gekennzeichnet, dass** das Mittel zum Hemmen in der Form von DNA vorliegt und aus einem Vektor besteht, der in der Lage ist, Nervenzellen und/oder Myozyten zu infizieren.

9. Mittel zum Hemmen zur Verwendung nach Anspruch 1, **dadurch gekennzeichnet, dass** das Mittel zum Hemmen durch eine Targetzelle exprimiert wird, nachdem das Mittel zum Hemmen zu der Zelle in Form von DNA unter

Anwendung eines geeigneten Vektors übertragen worden ist.

10. Mittel zum Hemmen zur Verwendung nach Anspruch 8, wobei der Vektor ein Virusvektor ist.

11. Mittel zum Hemmen zur Verwendung nach irgendeinem der Ansprüche 9 oder 10, wobei der Vektor ein Lentivirus ist.

Revendications

1. Agent inhibiteur de la phosphorylation par $p38^{MAPK}$ au niveau des résidus Thr248 et/ou Thr250 du facteur de transcription E2F4, pour son utilisation dans la prévention et/ou le traitement d'une pathologie associée à la polyploïdie somatique, l'agent inhibiteur étant
une forme mutante du facteur de transcription E2F4 avec SEQ ID NO : 1 substituée au niveau des résidus Thr248 et/ou Thr250 par un acide aminé qui ne peut être phosphorylé par $p38^{MAPK}$ autre que le glutamate ou l'aspartate ou une forme de E2F4 provenant d'une espèce autre qu'humaine avec des mutations sur les résidus Thr conservés aux positions localisées au sein d'une séquence conservée correspondant à Thr248 et/ou Thr250 de la séquence du E2F4 humain, lesdites mutations consistant en une substitution du résidu Thr conservé par un résidu qui ne peut être phosphorylé par $p38^{MAPK}$ autre que le glutamate ou l'aspartate,
et où ladite pathologie associée à la polyploïdie somatique est une maladie neurodégénérative.

2. Agent inhibiteur pour son utilisation selon la revendication 1, **caractérisé en ce que** ledit acide aminé qui ne peut pas être phosphorylé est l'alanine.

3. Agent inhibiteur pour son utilisation selon la revendication 1, **caractérisé en ce que** ladite forme de E2F4 provenant d'une autre espèce est choisie parmi SEQ ID NO 2 et/ou SEQ ID NO 3.

4. Agent inhibiteur pour son utilisation selon les revendications 1 à 3, **caractérisé en ce que** ladite polyploïdie somatique survient à la suite d'une endoréduplication dans des cellules post-mitotiques.

5. Agent inhibiteur pour son utilisation selon la revendication 4, **caractérisé en ce que** lesdites cellules post-mitotiques sont des neurones.

6. Agent inhibiteur pour son utilisation selon les revendications 1 à 5, **caractérisé en ce que** ladite maladie neurodégénérative est la maladie d'Alzheimer.

7. Agent inhibiteur pour son utilisation selon la revendication 1, **caractérisé en ce que** ledit agent inhibiteur est associé à un peptide perméable aux membranes cellulaires facilitant son incorporation dans la cellule.

8. Agent inhibiteur pour son utilisation selon la revendication 1, **caractérisé en ce que** ledit agent inhibiteur se présente sous la forme d'ADN et est compris dans un vecteur capable d'infecter des neurones et/ou des myocytes.

9. Agent inhibiteur pour son utilisation selon la revendication 1, **caractérisé en ce que** ledit agent inhibiteur est exprimé par une cellule cible après que ledit agent inhibiteur soit transféré à la cellule sous la forme d'ADN à l'aide d'un vecteur approprié.

10. Agent inhibiteur pour son utilisation selon la revendication 8, dans lequel le vecteur est un vecteur viral.

11. Agent inhibiteur pour son utilisation selon l'une quelconque des revendications 9 ou 10, dans lequel le vecteur est un lentivirus.

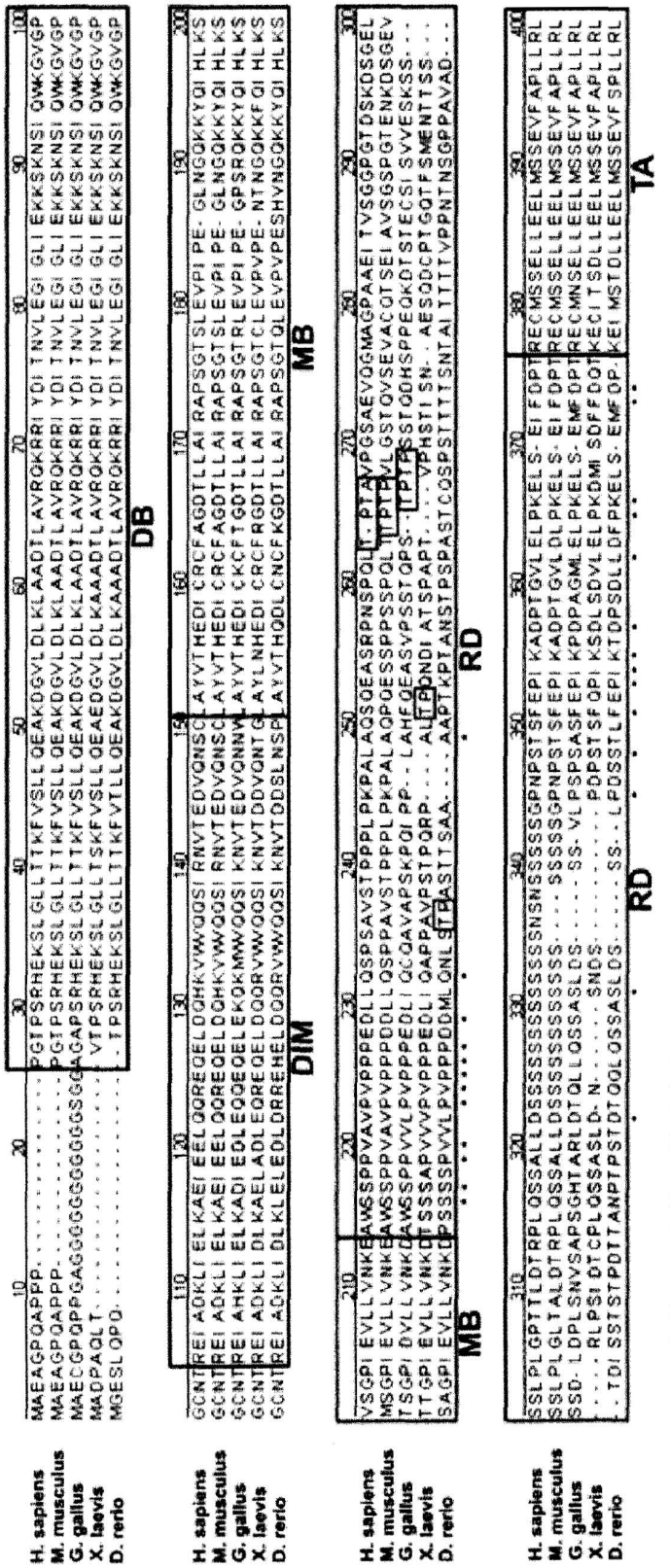


FIGURE 1

FIGURE 2

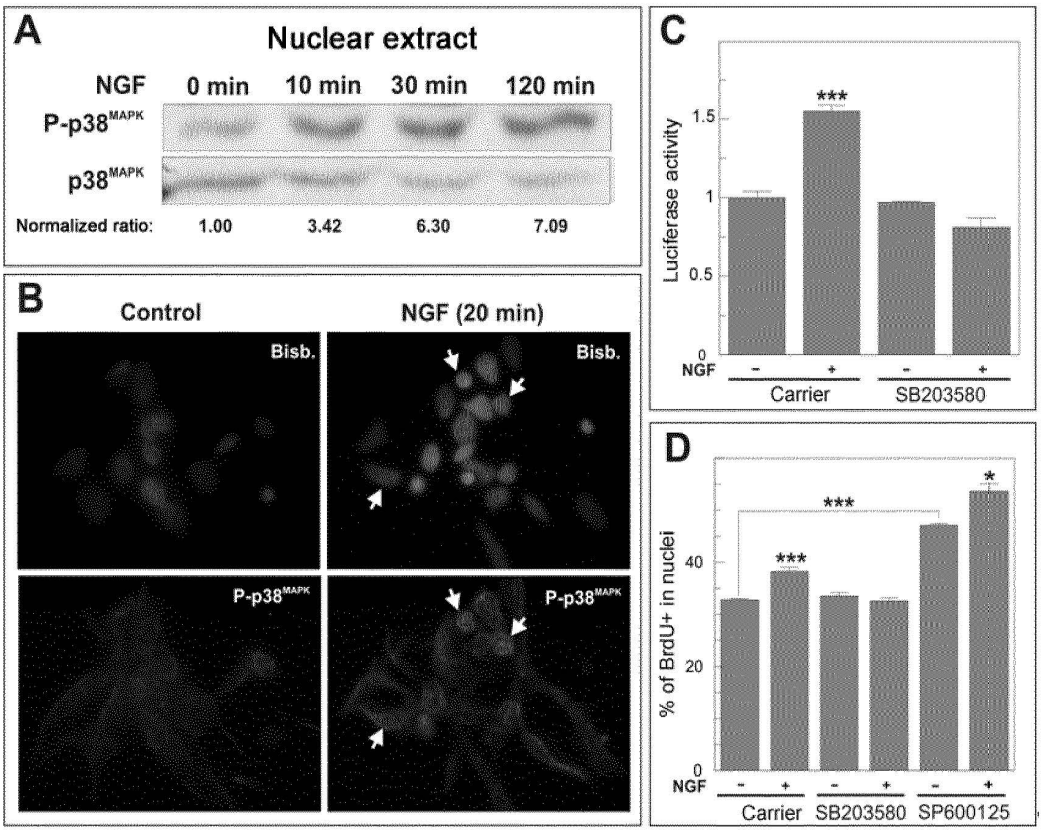


FIGURE 3

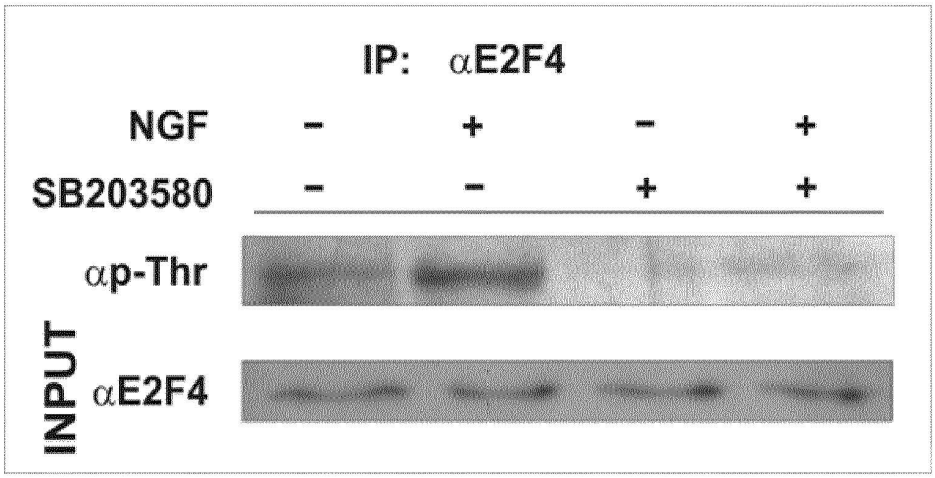


FIGURE 4

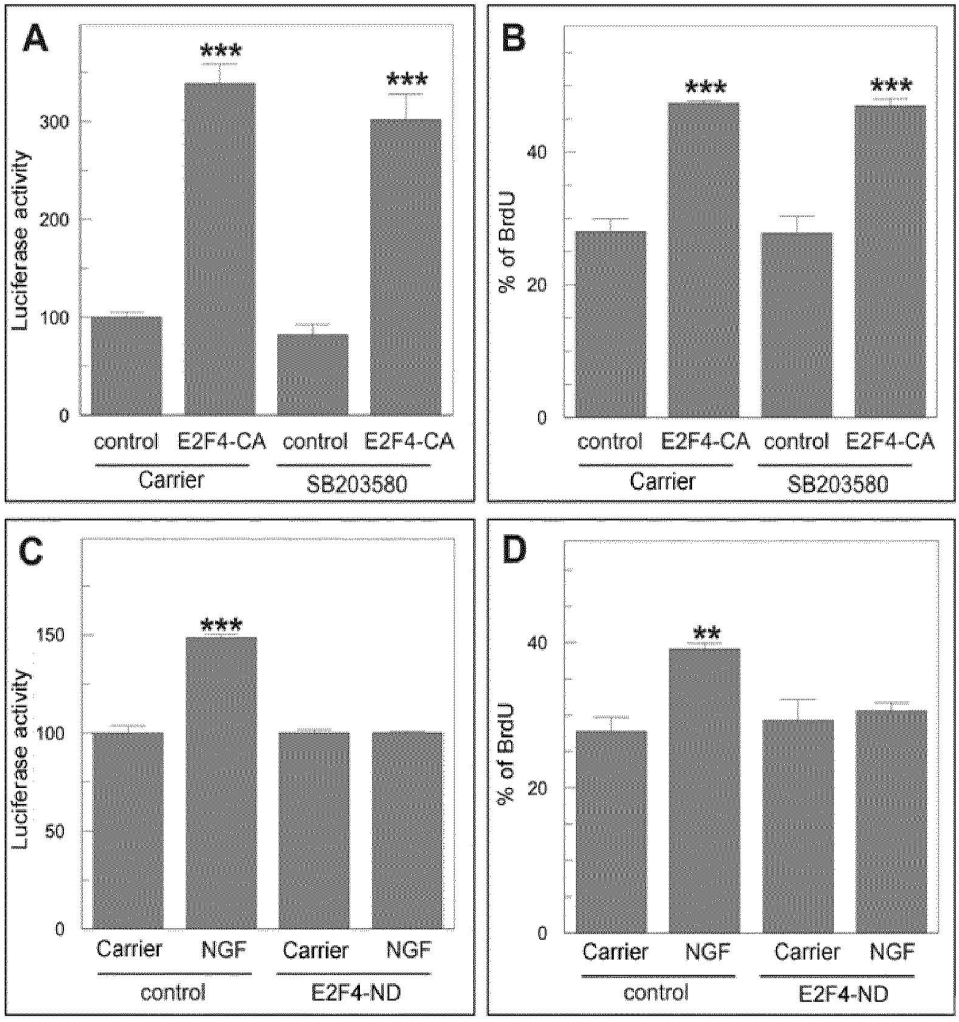

A
Luciferase activity
0
100
200
300
***
***
control
E2F4-CA
control
E2F4-CA
Carrier
SB203580
B
% of BrdU
0
20
40
***
***
control
E2F4-CA
control
E2F4-CA
Carrier
SB203580
C
Luciferase activity
0
50
100
150
***
Carrier
NGF
Carrier
NGF
control
E2F4-ND
D
% of BrdU
0
20
40
**
Carrier
NGF
Carrier
NGF
control
E2F4-ND

FIGURE 5

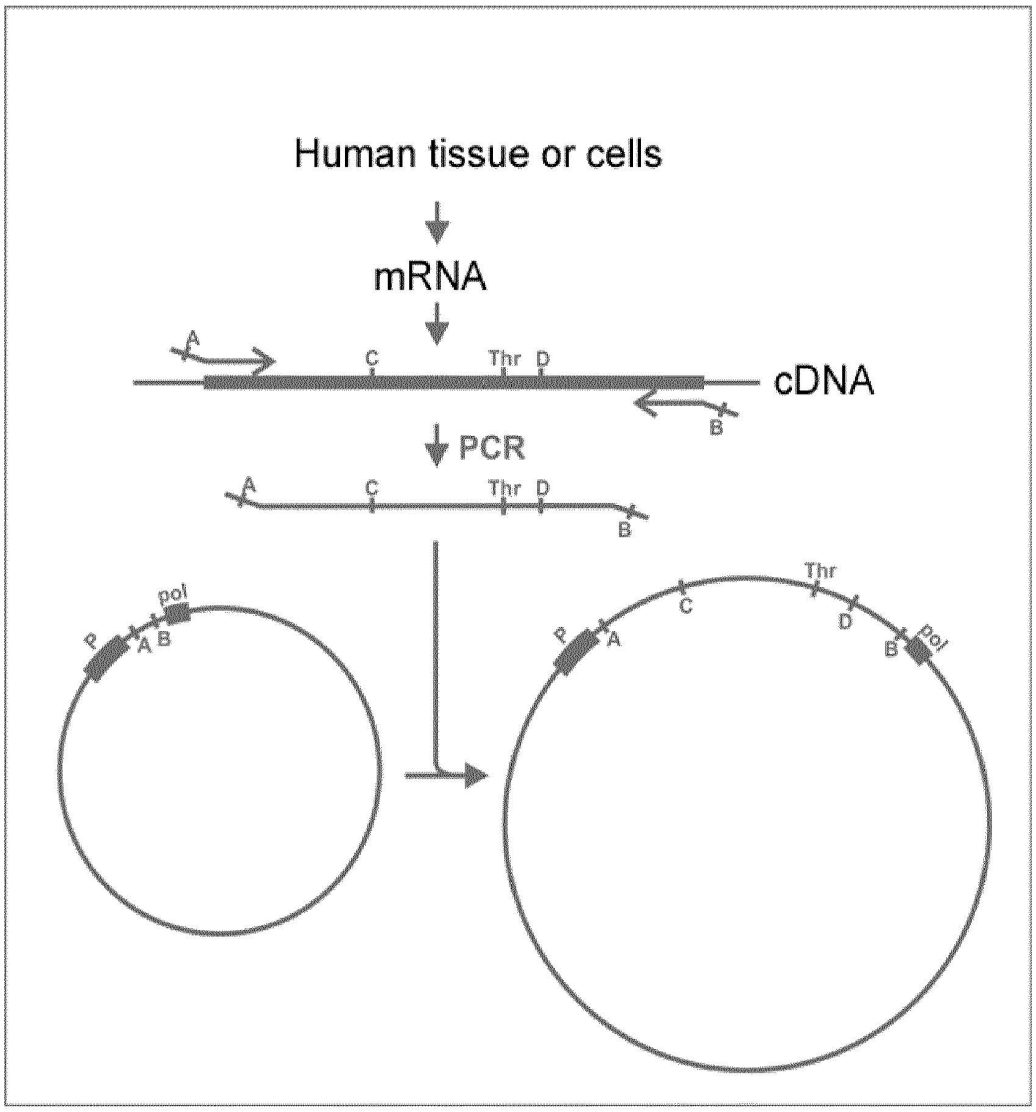
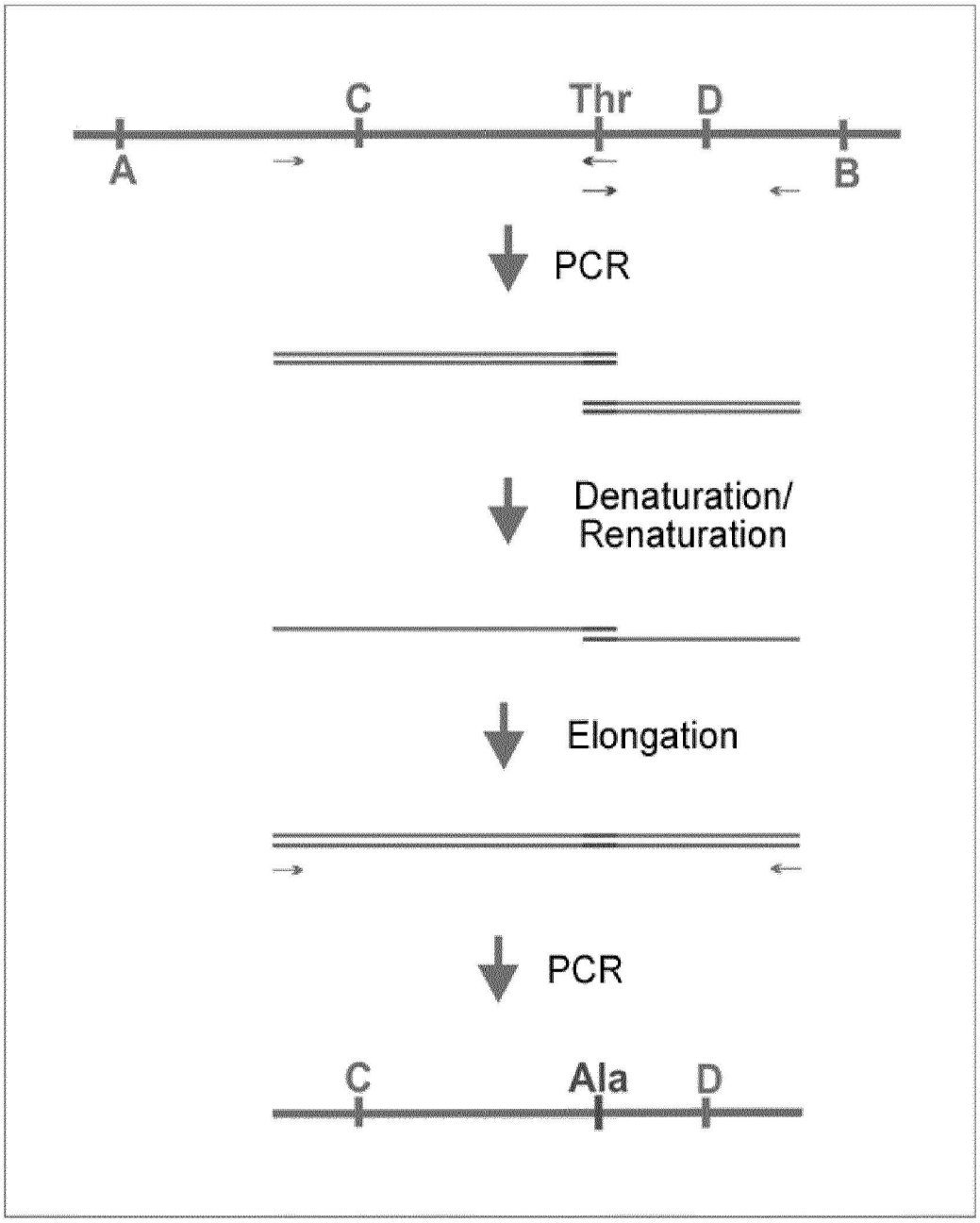

Human tissue or cells
mRNA
A
C
Thr
D
cDNA
B
PCR
A
C
Thr
D
B
pol
P
A
B
Thr
C
D
P
A
B
Pol

FIGURE 6


C
Thr
D
A
B
PCR
Denaturation/
Renaturation
Elongation
PCR
C
Ala
D

REFERENCES CITED IN THE DESCRIPTION

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