

Donecopride as neuroprotective agent in the treatment of neurodegenerative diseases

The present invention concerns the treatment of neurodegenerative diseases.

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Neurodegenerative diseases are those which are induced by the collapse of nervous circuit neural network based on the systematic degeneration and deciduation of neurocytes, and they have been known as various intractable diseases such as Alzheimer's disease (AD), Parkinson's disease, Lewis body dementia, vascular dementia, and problem associated with ageing including (i) non-cognitive neurodegeneration, (ii) non-cognitive neuromuscular degeneration and (iii) motor-sensory neurodegeneration, Huntington's disease, motor neurone diseases including amyotrophic lateral sclerosis (ALS), Down syndrome, corticobasal ganglionic degeneration, multiple system atrophy, cerebral atrophy, olivopontocerebellar atrophy, supranuclear palsy, Friedreich's ataxia, spinocerebellar ataxia type 2, frontotemporal degenerations (FTD) and primary progressive aphasia.

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Clinical symptoms of neurodegenerative diseases vary from minor ones to severe ones, depending on the disease. They include tremor, rigidity, akinesia, hypokinesia, bradykinesia, attitude reflex failure, dysautonomia, pulsion, gait disturbance, depression, apathy, confusion, learning alteration, memory deficits, cognitive impairment, amyotrophia, muscle loss, disorder of shoulder girdle, articulation disorder, dysphagia, respiration disorder, numbness, paralysis and dementia, which are major hurdles in performing daily activities.

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Neurodegenerative death is a complicated mechanism probably due to multiple molecular groups which trigger neurodegenerative diseases when issues in their expression, activity and/or regulation occur. This may explain why no effective method for inhibiting or reversing neurodegeneration has been established so far.

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In addition to the treatment for removing causatives of such diseases, it is also important to reconstruct the neural network. For example, there have been said that, in Alzheimer's disease for which cytotoxicity of amyloid β peptide has been recognized as a causative, both the atrophia of neurites and the reduction of synapses trigger off the deterioration of neurofunction, and in reverse, even after such triggering, neurocytes which are not fully denatured or survived without degeneration can be recovered if they can possibly be activated to extend neurites for recovering synapse.

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There is thus an important need for new agents capable of protecting neurites but also able to increase neurite growth and to promote the formation of new synapses, in order both to prevent and curatively treat neurodegenerative diseases.

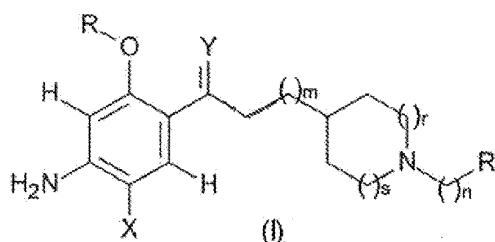
The present invention meets this need.

The present invention indeed results from the unexpected finding by the inventors that the Donecopride compound, disclosed in the international application WO 2014195593, has a neuroprotective activity since it is able, in addition to decrease Tau hyperphosphorylation, to increase neurite growth, to maintain the synapses rate, and most importantly and unexpectedly to promote formation of new synapses.

Because of this general and efficient protective effect on neurites, the Donecopride compound is a very promising neuroprotective agent for preventing and/or treating any neurodegenerative disease involving neurites degeneration.

This effect has further been confirmed with a high number of compounds of the general formula (I) below in numerous models of neurodegenerative diseases, in particular in Alzheimer's disease models, Parkinson's disease models, amyotrophic lateral sclerosis models, Huntington's disease models, and models of neurodegenerative diseases induced by ischemia or traumatic brain injuries.

The present invention thus concerns a compound of the following formula (I):



wherein:

X represents

a hydrogen atom, or

a halogen atom (Hal), where (Hal) is fluorine, chlorine, bromine or iodine, or

a straight- or branched-chain $C_p(\text{Hal})_{2p+1}$ polyhalogenoalkyl group, where $p=1, 2, 3$ or 4 , (Hal) having the same meaning as indicated above;

Y represents

an oxygen atom, or

a sulfur atom, or

an N-R" radical where R" represents a hydrogen atom, an -OH radical, an -O-A radical where A represents a straight- or branched-chain C₁-C₆ alkyl group, in particular where A represents a methyl group, or a straight- or branched-chain C_qH_{2q+1} alkyl radical, where

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q=1, 2, 3 or 4;

m is an integer selected from 1, 2 and 3;

n is an integer selected from 0, 1, 2 and 3;

r and s are integers whose values are: r=s=0; or r=s=1; or r=s=2; or r=0 and s=1; or lastly r=0 and s=2;

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R represents

a hydrogen atom, or

a straight- or branched-chain C₁-C₅ alkyl group capable of carrying one or more F atoms;

R' represents

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a branched-chain C₁-C₆ alkyl radical, or

a C₃-C₁₀ cycloalkyl or C₅-C₁₃ bicyclic group, capable of carrying one or more R groups and of possessing an oxygen atom, or a nitrogen atom that can be substituted by R, or a sulfur atom or a radical -SO₂- or -SO-,

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as well as its enantiomers or diastereoisomers and its racemics, its acid salts, its hydrates or its solvation products,

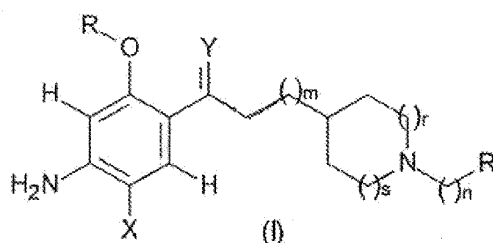
for use as neuroprotective agent in the prevention and/or treatment of a neurodegenerative disease.

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Detailed description of the invention

Compounds

The compound used in the context of the invention is a compound of the following formula (I):



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wherein:

X represents

a hydrogen atom, or
 a halogen atom (Hal), where (Hal) is fluorine, chlorine, bromine or iodine, or
 a straight- or branched-chain $C_p(\text{Hal})_{2p+1}$ polyhalogenoalkyl group,
 where $p=1, 2, 3$ or 4 , (Hal) having the same meaning as indicated
 above;

Y represents

an oxygen atom, or
 a sulfur atom, or
 an $N-R''$ radical where R'' represents a hydrogen atom, an $-OH$ radical, an $-O-A$ radical where A represents a straight- or branched-chain C_1-C_6 alkyl group, in particular where A represents a methyl group, or a straight- or branched-chain C_qH_{2q+1} alkyl radical, where $q=1, 2, 3$ or 4 ;

m is an integer selected from 1, 2 and 3;

n is an integer selected from 0, 1, 2 and 3;

r and s are integers whose values are: $r=s=0$; or $r=s=1$; or $r=s=2$; or $r=0$ and $s=1$; or lastly $r=0$ and $s=2$;

R represents

a hydrogen atom, or
 a straight- or branched-chain C_1-C_5 alkyl group capable of carrying one or more F atoms;

R' represents

a branched-chain C_1-C_6 alkyl radical, or
 a C_3-C_{10} cycloalkyl or C_5-C_{13} bicyclic group, capable of carrying one or more R groups and of possessing an oxygen atom, or a nitrogen atom that can be substituted by R, or a sulfur atom or a radical $-SO_2-$ or $-SO-$,

as well as its enantiomers or diastereoisomers and its racemics, its acid salts, its hydrates or its solvation products.

In a particular embodiment, in the formula (I), Y represents

an oxygen atom, or
 a sulfur atom, or
 an $N-R''$ radical where R'' represents a hydrogen atom, an $-OH$ radical, or a straight- or branched-chain C_qH_{2q+1} alkyl radical, where $q=1, 2, 3$ or 4 .

In a particular embodiment, in the formula (I), X represents a halogen atom, in particular a chlorine or a fluorine, more particularly a chlorine, most particularly a fluorine.

In another particular embodiment, in the formula (I), Y represents an oxygen atom.

5 In another particular embodiment, in the formula (I), all of m, n, r and s have the value 1.

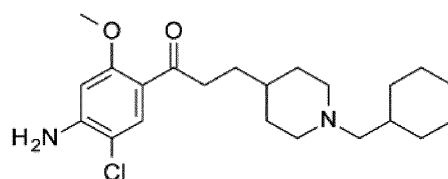
In another particular embodiment, in the formula (I), R represents H, CH₃, CH₂CH₃ or CH₂-CH₂F. Preferably, R represents CH₃.

10 In another particular embodiment, in the formula (I), R' represents a radical selected from the group consisting in the radicals cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl, 4-piperidine and -CH₂NHSO₂CH₃. In another particular embodiment, in the formula (I), R' represents a radical selected from the group consisting in the radicals cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, 4-piperidine and -CH₂NHSO₂CH₃. Preferably, in the formula (I), R' represents a radical selected from the group consisting in the radicals cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl and 4-piperidine. Preferably, in the formula (I), R' represents a radical selected from the group consisting in the radicals cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl and 4-piperidine. Still preferably, R' represents a C₄-C₇ cycloalkyl radical. Still preferably, R' represents a cyclopentyl radical, a cyclohexyl radical, a cycloheptyl radical or a 2-piperidine radical. More preferably, R' represents a cyclopentyl radical. Still preferably, R' represents a cyclohexyl radical. Still preferably, R' represents a 2-piperidine radical. Most preferably R' represents a cycloheptyl radical.

20 In another particular embodiment, in the formula (I), R represents CH₃ and R' represents a C₄-C₇ cycloalkyl radical, in particular a cyclohexyl radical. In another particular embodiment, in the formula (I), R represents CH₃ and R' represents a C₄-C₇ cycloalkyl radical, in particular a cyclopentyl radical. In another particular embodiment, in the formula (I), R represents CH₃ and R' represents a C₄-C₇ cycloalkyl radical, in particular a 2-piperidine radical. In another particular embodiment, in the formula (I), R represents CH₃ and R' represents a C₄-C₇ cycloalkyl radical, in particular a cycloheptyl radical.

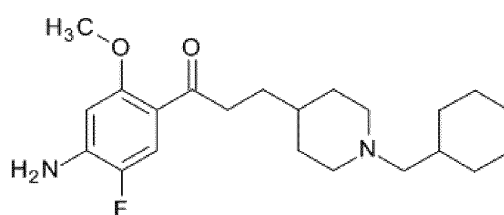
30 In a particularly preferred embodiment, in the formula (I), X represents a chlorine, Y represents an oxygen atom, all of m, n, r and s have the value 1, R represents CH₃ and R' represents a cyclohexyl radical. In other words, in a particularly preferred embodiment, the compound used in the context of the invention is the donecopride compound of following formula (II):

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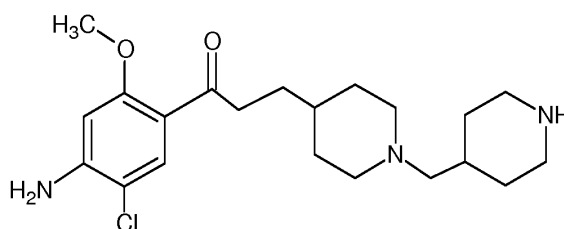
(II).

In another particularly preferred embodiment, in the formula (I), X represents a fluorine, Y represents an oxygen atom, all of m, n, r and s have the value 1, R represents CH₃ and R' represents a cyclohexyl radical. In other words, in a particularly preferred embodiment, the compound used in the context of the invention is the flucopride compound of following formula (III):



(III).

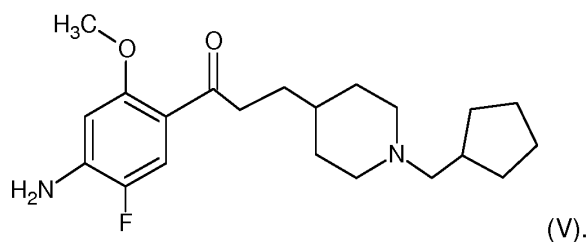
In another particularly preferred embodiment, in the formula (I), X represents a chlorine, Y represents an oxygen atom, all of m, n, r and s have the value 1, R represents CH₃ and R' represents a 2-piperidine radical. In other words, in a particularly preferred embodiment, the compound used in the context of the invention is the compound MR31176 of following formula (IV):



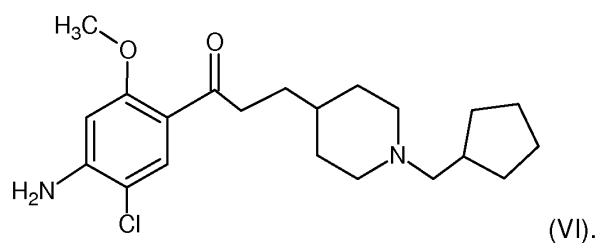
(IV).

In another particularly preferred embodiment, in the formula (I), X represents a fluorine, Y represents an oxygen atom, all of m, n, r and s have the value 1, R represents CH₃ and R' represents a cyclopentyl radical. In other words, in a particularly preferred embodiment, the compound used in the context of the invention is the compound MR33583 of following formula (V):

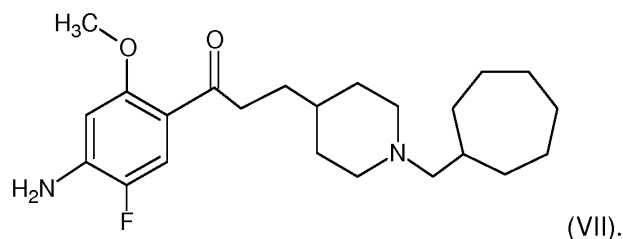
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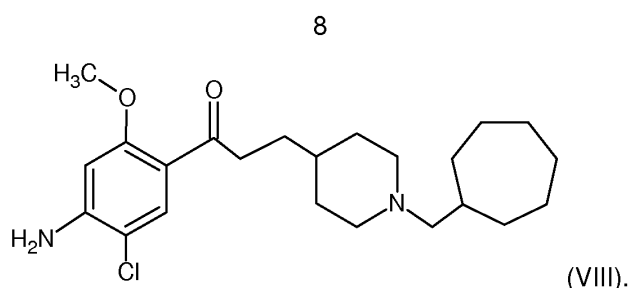
In another particularly preferred embodiment, in the formula (I), X represents a chlorine, Y represents an oxygen atom, all of m, n, r and s have the value 1, R represents CH₃ and R' represents a cyclopentyl radical. In other words, in a particularly preferred embodiment, the compound used in the context of the invention is the compound MR31172 of following formula (VI):



In another particularly preferred embodiment, in the formula (I), X represents a fluorine, Y represents an oxygen atom, all of m, n, r and s have the value 1, R represents CH₃ and R' represents a cycloheptyl radical. In other words, in a particularly preferred embodiment, the compound used in the context of the invention is the compound MR36014 of following formula (VII):



In another most preferred embodiment, in the formula (I), X represents a chlorine, Y represents an oxygen atom, all of m, n, r and s have the value 1, R represents CH₃ and R' represents a cycloheptyl radical. In other words, in a particularly preferred embodiment, the compound used in the context of the invention is the compound MR31192 of following formula (VIII):



In another particular embodiment, X represents a chlorine, Y represents an N-R" radical where R" represents an -O-A radical where A represents a methyl group, all of m, n, r and s have the value 1, R represents CH₃ and R' represents a cyclohexyl radical. In other words, in a particular embodiment, the compound used in the context of the invention is the compound 2-chloro-4-[[2-[1-(cyclohexylmethyl)-4-piperidyl] ethyl]-N-methoxycarbonimidoyl]-5-methoxyaniline.

In particular embodiments, acid salts of the above-defined compounds are used. In more particular embodiment, said acid salts are fumarates or dihydrochlorates.

More particularly, in a particularly preferred embodiment, the compound used in the context of the invention is Donecopride (of formula (II) above) fumarate, in particular Donecopride fumarate hydrate.

In another particularly preferred embodiment, the compound used in the context of the invention is fluocopride (of formula (III) above) fumarate.

In another particularly preferred embodiment, the compound used in the context of the invention is MR31176 (of formula (IV) above) dihydrochlorate, in particular dihydrochlorate dehydrate.

In another particularly preferred embodiment, the compound used in the content of the invention is MR33583 (of formula (V) above) fumarate.

In another particularly preferred embodiment, the compound used in the content of the invention is MR31172 (of formula (VI) above) fumarate.

In another particularly preferred embodiment, the compound used in the content of the invention is MR36014 (of formula (VII) above) fumarate.

In another particularly preferred embodiment, the compound used in the content of the invention is MR31192 (of formula (VIII) above) fumarate.

Neurodegenerative disease

By "neurodegenerative disease" is meant herein a disease induced by the collapse of nervous circuit neural network based on the systematic degeneration and decudation of neurocytes.

As explained above, the present inventors demonstrated that Donecopride displayed a general and efficient protective effect on neurites. Because of this general neuroprotective effect, Donecopride can be used as neuroprotective agent for preventing and/or treating any neurodegenerative disease.

5 The inventors further confirmed this effect with a high number of compounds of the general formula (I) above, in particular the compounds specifically defined in section "Compounds" above, in numerous models of neurodegenerative diseases, in particular in Alzheimer's disease models, Parkinson's disease models, amyotrophic lateral sclerosis models, Huntington's disease models, and models of neurodegenerative diseases
10 induced by ischemia or traumatic brain injuries.

 Examples of neurodegenerative disease include Alzheimer's disease (AD), Parkinson's disease, Lewis body dementia, vascular dementia, and problem associated with ageing including (i) non-cognitive neurodegeneration, (ii) non-cognitive neuromuscular degeneration and (iii) motor-sensory neurodegeneration, Huntington's
15 disease, motor neurone diseases including amyotrophic lateral sclerosis (ALS), Down syndrome, corticobasal ganglionic degeneration, multiple system atrophy, cerebral atrophy, olivopontocerebellar atrophy, supranuclear palsy, Friedreich's ataxia, spinocerebellar ataxia type 2, frontotemporal degenerations (FTD) and primary progressive aphasia.

20 In a particular embodiment, the neurodegenerative disease is selected from the group consisting of Alzheimer's disease, Parkinson's disease, Huntington's disease, multiple system atrophy, motor neuron diseases including amyotrophic lateral sclerosis, Down syndrome and frontotemporal degenerations.

 In a more particular embodiment, the neurodegenerative disease is selected from
25 the group consisting of Alzheimer's disease, Parkinson's disease, Huntington's disease, and amyotrophic lateral sclerosis.

 In another embodiment, the neurodegenerative disease is Alzheimer's disease.

 In an alternative embodiment, the neurodegenerative disease is a neurodegenerative disease which is not Alzheimer's disease.

30 In said alternative embodiment, the neurodegenerative disease is selected from the group consisting of Parkinson's disease, Huntington's disease, and amyotrophic lateral sclerosis.

Medical indications

35 The present invention relates to a compound as defined in the section "Compounds" above for use as neuroprotective agent in the prevention and/or treatment

of a neurodegenerative disease as defined in the section "*Neurodegenerative disease*" above.

The present invention also concerns the use of a compound as defined in the section "*Compounds*" above for the manufacture of a neuroprotective agent for the prevention and/or treatment of a neurodegenerative disease as defined in the section "*Neurodegenerative disease*" above.

The present invention further concerns a method of preventing and/or treating a neurodegenerative disease as defined in the section "*Neurodegenerative disease*" above, comprising administering to a subject in need thereof a therapeutically efficient amount of a compound as defined in the section "*Compounds*" above as neuroprotective agent.

The present invention further concerns a method of neuroprotection in a subject suffering from, or at risk of suffering from a neurodegenerative disease as defined in the section "*Neurodegenerative disease*" above, comprising administering to said subject a therapeutically efficient amount of a compound as defined in the section "*Compounds*" above.

According to the invention, the term "subject" or "subject in need thereof" is intended for a human or non-human mammal affected or likely to be affected with a neurodegenerative disease as defined in the section "*Neurodegenerative diseases*" above.

In the context of the invention, the term "treating" or "treatment" means reversing, alleviating or inhibiting the progress of the disorder or condition to which such term applies, or one or more symptoms of such disorder or condition.

In the context of the invention, the term "preventing" or "prevention" means delaying or preventing the onset of the disorder or condition to which such term applies, or one or more symptoms of such disorder or condition.

By "neuroprotection" is meant herein the prevention or inhibition of degenerative effects and restauration of neuronal integrity in the central nervous system, in particular the prevention or inhibition of neuronal degeneration.

By "neuroprotective agent" is meant herein an agent able of neuroprotection as defined above.

The inventors more particularly demonstrated that the compounds used in the context of the invention were capable of increasing neurite growth, maintaining synapses rate, decreasing Tau hyperphosphorylation and/or promoting formation of new synapses.

Accordingly, in a particular embodiment, the compound as defined in the section "*Compounds*" above is for increasing neurite growth.

The present invention also concerns a method for increasing neurite growth in a subject suffering from, or at risk of suffering from a neurodegenerative disease as defined in the section "*Neurodegenerative disease*" above, comprising administering to said subject a therapeutically efficient amount of a compound as defined in the section

5 "*Compounds*" above.

By "neurite growth" is meant herein the extension process of any projection from the cell body of a neuron and associated synapse genesis.

By "increasing neurite growth" is meant herein that the growth of neurites is higher (*i.e.* more efficient, faster or longer), preferably statistically significantly higher, when the compound of interest is applied compared to the growth of neurites observed in the same conditions but without applying the compound of interest. Preferably, the neurite growth is increased of at least 120% compared to growth of neurites observed in the same conditions but without applying the compound of interest.

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In another particular embodiment, the compound as defined in the section

15 "*Compounds*" above is for maintaining synapses rate.

Another object of the present invention concerns a method for maintaining synapses rate in a subject suffering from, or at risk of suffering from a neurodegenerative disease as defined in the section "*Neurodegenerative disease*" above, comprising administering to said subject a therapeutically efficient amount of a compound as defined

20 in the section "*Compounds*" above.

By "synapses rate" is meant herein the ratio of the number of synapses and the number of neurons.

By "maintaining synapses rate" is meant herein that the synapses rate is similar (*i.e.* not statistically significantly different) when the compound of interest is applied compared to the synapses rate observed in control conditions, such as same conditions but without applying the compound of interest or conditions where the neurons are not faced to neurodegenerative conditions.

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In another particular embodiment, the compound as defined in the section

30 "*Compounds*" above is for promoting formation of new synapses.

Another object of the present invention concerns a method for promoting formation of new synapses in a subject suffering from, or at risk of suffering from a neurodegenerative disease as defined in the section "*Neurodegenerative disease*" above, comprising administering to said subject a therapeutically efficient amount of a compound as defined in the section "*Compounds*" above.

By "promoting formation of new synapses" is meant herein that the number of newly formed synapses is higher, preferably statistically significantly higher, when the

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compound of interest is applied compared to the number of newly formed synapses observed in the same conditions but without applying the compound of interest. Preferably, the formation of new synapses is increased of at least 120% compared to formation of new synapses observed in the same conditions but without applying the compound of interest.

In another particular embodiment, the compound as defined in the section "*Compounds*" above is for decreasing Tau hyperphosphorylation.

Another object of the present invention concerns a method for decreasing Tau phosphorylation in a subject suffering from, or at risk of suffering from a neurodegenerative disease as defined in the section "*Neurodegenerative disease*" above, comprising administering to said subject a therapeutically efficient amount of a compound as defined in the section "*Compounds*" above.

By "Tau hyperphosphorylation" is meant herein the abnormally high phosphorylation of the Tau protein, in particular the abnormal phosphorylation of the Tau protein at least one of the Thr39, Ser46, Thr50, Ser68, Thr69, Thr71, Ser113, Thr153, Thr175, Thr181, Ser184, Ser185, Ser191, Ser198, Ser199, Ser202, Thr205, Ser208, Ser210, Thr212, Ser214, Thr217, Thr231, Ser235, Ser237, Ser238, Ser241, Ser258, Ser262, Ser285, Ser289, Ser305, Ser324, Ser352, Ser356, Tyr394, Ser396, Ser400, Thr403, Ser404, Ser409, Ser412, Ser413, Thr414, Ser416, Ser422, Ser433 and Ser435 residues.

By "decreasing Tau hyperphosphorylation" is meant herein that at least one of the Thr39, Ser46, Thr50, Ser68, Thr69, Thr71, Ser113, Thr153, Thr175, Thr181, Ser184, Ser185, Ser191, Ser198, Ser199, Ser202, Thr205, Ser208, Ser210, Thr212, Ser214, Thr217, Thr231, Ser235, Ser237, Ser238, Ser241, Ser258, Ser262, Ser285, Ser289, Ser305, Ser324, Ser352, Ser356, Tyr394, Ser396, Ser400, Thr403, Ser404, Ser409, Ser412, Ser413, Thr414, Ser416, Ser422, Ser433 and Ser435 residues, in particular one of Ser212 and Thr214 residues of the Tau protein is not abnormally phosphorylated when the compound of interest is applied whereas said residue is abnormally phosphorylated in the same conditions but without applying the compound of interest.

By "therapeutically effective amount" is meant herein sufficient amount of the compound to act as neuroprotective agent in the treatment and/or prevention of a neurodegenerative disease at a reasonable benefit/risk ratio applicable to any medical treatment. It will be understood, however, that the total daily usage of the compounds of the present invention will be decided by the attending physician within the scope of sound medical judgment. The specific therapeutically effective dose level for any particular subject will depend upon a variety of factors including the disorder being treating and the

severity of the disorder, activity of the specific compounds employed, the age, body weight, general health, sex and diet of the subject, the time of administration, route of administration and rate of excretion of the specific compounds employed, the duration of the treatment, drugs used in combination or coincidental with the specific compounds employed, and like factors well known in the medical arts. For example, it is well within the skill of the art to start doses of the compounds at levels lower than those required to achieve the desired therapeutic effect and to gradually increase the dosage until the desired effect is achieved.

The compounds used in the context of the invention may be administered in the form of a pharmaceutical composition including pharmaceutically acceptable excipients, and optionally sustained-release matrices, such as biodegradable polymers, to form therapeutic compositions.

"Pharmaceutically" or "pharmaceutically acceptable" refers to molecular entities and compositions that do not produce an adverse, allergic or other untoward reaction when administered to a mammal, especially a human, as appropriate. A pharmaceutically acceptable carrier or excipient refers to a non-toxic solid, semi-solid or liquid filler, diluent, encapsulating material or formulation auxiliary of any type.

The form of the pharmaceutical compositions including the compounds used in the context of the invention and the route of administration naturally depend upon the condition to be treated, the severity of the illness, the age, weight, and gender of the patient, etc.

The compounds used in the context of the invention can be formulated for a topical, oral, parenteral, intranasal, intravenous, intramuscular, subcutaneous or intraocular administration and the like. In a particular embodiment, the compound used in the context of the invention is administered orally.

Alternatively, the pharmaceutical compositions including the compounds used in the context of the invention may contain vehicles which are pharmaceutically acceptable for a formulation capable of being injected. These may be in particular isotonic, sterile, saline solutions (monosodium or disodium phosphate, sodium, potassium, calcium or magnesium chloride and the like or mixtures of such salts), or dry, especially freeze-dried compositions which upon addition, depending on the case, of sterilized water or physiological saline, permit the constitution of injectable solutions.

To prepare pharmaceutical compositions, an effective amount of the compounds used in the context of the invention may be dissolved or dispersed in a pharmaceutically acceptable carrier or aqueous medium.

The pharmaceutical forms suitable for injectable use include sterile aqueous solutions or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersions. In all cases, the form must be sterile and must be fluid to the extent that easy syringability exists. It must be stable under the conditions of manufacture and storage and must be preserved against the contaminating action of microorganisms, such as bacteria and fungi.

The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol, and the like) and suitable mixtures thereof. The proper fluidity can be maintained, for example, by the use of a coating, such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants, stabilizing agents, cryoprotectants or antioxidants. The prevention of the action of microorganisms can be brought about by antibacterial and antifungal agents. In many cases, it will be preferable to include isotonic agents, for example, sugars or sodium chloride.

Sterile injectable solutions are prepared by incorporating the active compounds in the required amount in the appropriate solvent with several of the other ingredients enumerated above, as required, followed by filtered sterilization. Generally, dispersions are prepared by incorporating the various sterilized active ingredients into a sterile vehicle which contains the basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum-drying and freeze-drying techniques which yield a powder of the active ingredient plus any additional desired ingredient from a previously sterile-filtered solution thereof.

Upon formulation, solutions will be administered in a manner compatible with the dosage formulation and in such amount as is therapeutically effective. The formulations are easily administered in a variety of dosage forms, such as the type of injectable solutions described above, but drug release capsules and the like can also be employed.

For parenteral administration in an aqueous solution, for example, the solution should be suitably buffered if necessary and the liquid diluent first rendered isotonic with sufficient saline or glucose. These particular aqueous solutions are especially suitable for intravenous, intramuscular, subcutaneous and intraperitoneal administration. In this connection, sterile aqueous media which can be employed will be known to those of skill in the art in light of the present disclosure. For example, one dosage could be dissolved in 1 mL of isotonic NaCl solution and either added to 1000 mL of hypodermoclysis fluid or injected at the proposed site of infusion, (see for example, "Remington's Pharmaceutical Sciences" 15th Edition, pages 1035-1038 and 1570-1580). Some variation in dosage will

necessarily occur depending on the condition of the subject being treated. The person responsible for administration will, in any event, determine the appropriate dose for the individual subject.

5 The compound used in the context of the invention can typically be administered orally for example in the form of tablets, capsules, microcapsules, powders, granules, syrups, solutions or suspensions taken by the oral or sublingual route.

In a particular embodiment, the compound used in the context of the invention is suitably administered orally at a daily dose of 1 to 20 mg/kg of body weight, in particular at a daily dose of 2 mg/kg.

10 In another particular embodiment, the compounds used in the context of the invention are suitably administered orally, twice a week, at a dose of 1 to 20 mg/kg of body weight, in particular at a dose of 1 mg/kg twice a week.

According to another particular embodiment, the compound used in the context of the invention is administered at doses of 10 to 1000 mg per day, preferably at doses of 0.2 to 2 mg 5 times a day.

The present invention will be further illustrated by the figures and examples below.

20 **Brief description of the figures**

Figure 1: Effect of MR31193 on survival of MAP-2 neurons (A), total neurite network (B), neurite length normalized by the number of neurons (C), and on the phosphorylation of Tau (AT100) (D) in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

30 **Figure 2:** Effect of MR31193 on the preservation of synapses of MAP-2 neurons in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

35 **Figure 3:** Effect of MR31176 on survival of MAP-2 neurons (A), total neurite network (B), neurite length normalized by the number of neurons (C), and on the phosphorylation of Tau (AT100) (D) in a primary culture of hippocampal neurons injured with A β 1-42.

Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 4: Effect of MR31176 on the preservation of synapses of MAP-2 neurons in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 5: Effect of MR31192 on survival of MAP-2 neurons (A), total neurite network (B), neurite length normalized by the number of neurons (C), and on the phosphorylation of Tau (AT100) (D) in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 6: Effect of MR31192 on the preservation of synapses of MAP-2 neurons in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 7: Effect of MR33583 on survival of MAP-2 neurons (A), total neurite network (B), neurite length normalized by the number of neurons (C), and on the phosphorylation of Tau (AT100) (D) in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 8: Effect of MR33583 on the preservation of synapses of MAP-2 neurons in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 9: Effect of MR31192 or Donepezil on survival of MAP-2 neurons (A), total neurite network (B), neurite length normalized by the number of neurons (C), and on the phosphorylation of Tau (AT100) (D) in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 10: Effect of MR31192 or Donepezil on the preservation of synapses of MAP-2 neurons in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 11: Effect of MR36014 or Donepezil on survival of MAP-2 neurons (A), total neurite network (B), neurite length normalized by the number of neurons (C), and on the phosphorylation of Tau (AT100) (D) in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 12: Effect of MR36014 or Donepezil on the preservation of synapses of MAP-2 neurons in a primary culture of hippocampal neurons injured with A β 1-42. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 13: Effect of MR36014 on survival of TH neurons (A), on the total neurite network of TH neurons (B), and on the aggregation of aSyn in TH neurons (C) in a primary culture of mesencephalic neurons injured with MPP⁺. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 14: Effect of MR33583 on survival of TH neurons (A), on the total neurite network of TH neurons (B), and on the aggregation of aSyn in TH neurons (C) in a primary culture of mesencephalic neurons injured with MPP⁺. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 15: Effect of MR36014 (A-B) and MR33583 (C-D) on the survival of MAP-2 neurons (A-C) and the protection of the total neurite network (B-D) in a primary culture of cortical neurons injured with glutamate. Results are expressed as a percentage of control as mean $\pm$ SEM (n=4-6/group). One-way ANOVA followed by LSD Fisher's test. *p< 0.05 was considered significant.

Figure 16: Effect of MR36014 on the survival (A) and neurite network (B, C) in spinal motor neurons, after glutamate injury. Results are expressed as percentage of control show the mean $\pm$ SEM (100% = CT, no compound). One-way ANOVA followed by Fisher LSD's test, n=4-6. p< 0.05 was considered significant.

5

Figure 17: Effect of MR33583 on the survival (A), neurite network (B, C) and on the cytoplasmic translocation of TDP-43 (D) in spinal motor neurons, after glutamate injury. Results are expressed as percentage of control show the mean $\pm$ SEM (100% = CT, no compound). One-way ANOVA followed by Fisher LSD's test, n=4-6. p< 0.05 was considered significant.

10

Figure 18: Effect of MR33583 on GABAergic neuron survival in a primary culture of mesencephalic cells, after deprivation of growth factors. Results are expressed as percentage of control show the mean $\pm$ SEM (100% = CT, no compound). One-way ANOVA followed by Fisher LSD's test, n=4-6. p< 0.05 was considered significant.

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Examples

20

Example 1

This example shows the effect of Donecopride in rat primary hippocampal neurons injured with A β (24h exposure).

25

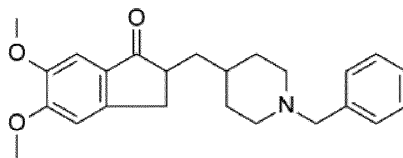
Alzheimer disease (AD) is a neurodegenerative disease which affects mainly people over the age of 65, suffering from different clinical symptoms such as progressive decline in thinking, language, and learning capacity. Increasing evidence from various sources points to A β Oligomers (A β O)/protofibrils as putative toxic species in AD pathogenesis.

30

By generating a solution of A β O and playing on the concentration of and time of exposure to A β O, it was possible to reproduce early effects (oxidative stress) and the long-term development of structural alterations (death of neurons).

The model used in the present example, using A β peptide solution containing A β O (precisely measured by automatic Western Blot), reproduced essential neuropathological features of AD.

The aim of this study was to evaluate the effects of one test compound (Donecopride fumarate at several concentrations) in rat primary hippocampal neurons injured with A β (24h exposure). Donepezil of the following formula :



5 (one concentration) was used as reference test compound.

Materials and methods

Primary culture of hippocampal neurons

10 Rat hippocampal neurons were cultured as described by Callizot *et al.* (2013) *J. Neurosci. Res.* **91**706-716. Pregnant female rats of 17 days gestation (Rats Wistar; Janvier Labs France) were killed using a deep anesthesia with CO₂ chamber followed by a cervical dislocation. Then, fetuses were removed from the uterus and immediately placed in ice-cold L15 Leibovitz medium with a 2% penicillin (10,000 U/ml) and streptomycin (10 mg/ml) solution (PS) and 1% bovine serum albumin (BSA). Hippocampal
15 neurons were treated for 20 min at 37°C with a trypsin-EDTA solution at a final concentration of 0.05% trypsin and 0.02% EDTA. The dissociation was stopped by adding Dulbecco's modified Eagle's medium (DMEM) with 4.5 g/l of glucose, containing DNase I grade II (final concentration 0.5 mg/ml) and 10% fetal calf serum (FCS). Cells were mechanically dissociated by three forced passages through the tip of a 10-ml pipette and
20 then centrifuged at 515 x g for 10 min at 4°C. The supernatant was discarded, and the pellet was resuspended in a defined culture medium consisting of Neurobasal medium with a 2% solution of B27 supplement, 2 mmol/l of L-glutamine, 2% of PS solution, and 10 ng/ml of brain-derived neurotrophic factor (BDNF). Viable cells were counted in a Neubauer cytometer, using the trypan blue exclusion test. Cells were seeded at a density
25 of 20,000 per well in 96-well plates precoated with poly-L-lysine and cultured at 37°C in an air (95%)-CO₂ (5%) incubator. The medium was changed every 2 days.

Donecopride and human A β 1-42 exposure

30 The hippocampal neurons were exposed with A β solutions (see below) after 17 days of culture. The A β 1-42 preparation was done following the procedure described by Callizot *et al.* (2013) *J. Neurosci. Res.* **91**706-716. Briefly, A β 1-42 peptide was dissolved in the defined culture medium mentioned above, at an initial concentration of 40 μ M. This solution was gently agitated for 3 days at 37°C in the dark and immediately used after

being properly diluted in culture medium to the concentrations used (20 μ M (plate 1) or 2.5 μ M (plate 2) corresponding to 2 μ M or 0.25 μ M of oligomers (A β O) respectively).

Donecopride fumarate was solved in culture medium and preincubated 1 h before A β application. A β 1-42 preparation was added to a final concentration of 20 or 2.5 μ M (= 2 μ M or 0.25 μ M of A β O, evaluated by automatic Western Blot) diluted in control medium in presence of Donecopride.

Organization of culture plates

Donecopride fumarate (Donecopride) was tested on one culture in a 96 well plate (6 wells per conditions). The compound was preincubated one hour before A β application. The following conditions were assessed:

PLATE 1 (MAP-2 / Tau)	PLATE 2 (PSD95 / SYN)
Control (Vehicle)	Control (Vehicle)
+ A β (20 μ M 24 h) / vehicle	+ A β (2.5 μ M 24 h) / vehicle
+ A β (20 μ M 24 h) / Donecopride (1 μ M)	+ A β (2.5 μ M 24 h) / Donecopride (1 μ M)
+ A β (20 μ M 24 h) / Donecopride (500 nM)	+ A β (2.5 μ M 24 h) / Donecopride (500 nM)
+ A β (20 μ M 24 h) / Donecopride (100 nM)	+ A β (2.5 μ M 24 h) / Donecopride (100 nM)
+ A β (20 μ M 24 h) / Donecopride (50 nM)	+ A β (2.5 μ M 24 h) / Donecopride (50 nM)
+ A β (20 μ M 24 h) / Donecopride (10 nM)	+ A β (2.5 μ M 24 h) / Donecopride (10 nM)
+ A β (20 μ M 24 h) / Donecopride (5 nM)	+ A β (2.5 μ M 24 h) / Donecopride (5 nM)
+ A β (20 μ M 24 h) / Donecopride (1 nM)	+ A β (2.5 μ M 24 h) / Donecopride (1 nM)
+ A β (20 μ M 24 h) / Donepezil (1 μ M)	+ A β (2.5 μ M 24 h) / Donepezil (1 μ M)

End point evaluation

Plate 1: SURVIVAL, NEURITE NETWORK AND PHOSPHO TAU EVALUATION

24 hours after intoxication, the hippocampal neurons were fixed by a cold solution of ethanol (95%) and acetic acid (5%) for 5 min at -20°C. After permeabilization with 0.1% of saponin, cells were incubated for 2 h with:

a) chicken polyclonal antibody anti microtubule-associated-protein 2 (MAP-2), diluted at 1/1000 in PBS containing 1% fetal calf serum and 0.1% of saponin (this antibody allows the specific staining of neuronal cell bodies and neurites; and allow the study of neuronal cell death and neurite network).

b) mouse monoclonal antibody anti-phospho Tau (AT100) at dilution of 1/400 in PBS containing 1% fetal calf serum and 0.1% of saponin.

These antibodies were revealed with Alexa Fluor 488 goat anti mouse IgG and Alexa Fluor 568 goat anti-chicken IgG at the dilution 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.

For each condition, 30 pictures (representative of the whole well area) per well were taken using ImageXpress (Molecular Devices) at 20x magnification. All images were

taken with the same acquisition parameters. Analyses were performed automatically by using Custom Module Editor (Molecular Devices).

The following endpoints were assessed:

- Total number of neurons (neuron survival, number of MAP-2 positive neurons)
- Neurite network (in μm of MAP-2 positive neurons)
- area of tau in neurons (μm^2 , overlapping with MAP-2 positive neurons).

Plate 2: SYNAPSES EVALUATION

24 hours after intoxication, the hippocampal neurons were fixed by a cold solution of ethanol (95%) and acetic acid (5%) for 5 min at -20°C . After permeabilization with 0.1% of saponin, cells were incubated for 2 h with:

- a) mouse monoclonal antibody anti post synaptic density 95kDa (PSD95) at a dilution of 1/100 in PBS containing 1% fetal calf serum and 0.1% of saponin.
- b) Rabbit polyclonal antibody anti-synaptophysin (SYN) at the dilution of 1/100 in PBS containing 1% fetal calf serum and 0.1% of saponin.

These antibodies were revealed with Alexa Fluor 488 goat anti mouse IgG and Alexa Fluor 568 goat anti-rabbit IgG at the dilution 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.

For each condition, 40 pictures per well were taken using ImageXpress (Molecular Devices) with 40x magnification. All images were taken with the same acquisition parameters.

Synapses evaluation was performed automatically by using Custom module editor (Molecular Devices).

The following endpoints were assessed:

- Total number of synapses (overlapping between PSD95/SYN).

Statistical analysis

All values are expressed as mean $\pm$ SEM. Statistical analysis was performed by one-way ANOVA, followed by PLSD Fisher's test, $p < 0.05$ were considered significant.

Graphs and statistical analyses on the different conditions were performed using GraphPad Prism software version 7.04. * $p < 0.05$ was considered significant.

Results

Effects of Donecopride on the survival and neurite network of MAP-2 hippocampal neurons and on the hyperphosphorylation of Tau.

Neuronal survival

The effect of Donecopride on the survival of MAP-2 neurons in a primary culture of hippocampal neurons is shown in Table 1 below.

5

Table 1: MAP-2 neurons (% of control)

	MAP-2 neurons (% of control)		
	mean	sem	n
Control	100	5	6
+ A β 1-42 (20 μ M)	70	2	6
+ Donecopride (1 nM)	70	2	5
+ Donecopride (5 nM)	69	2	6
+ Donecopride (10 nM)	73	2	5
+ Donecopride (50 nM)	74	2	5
+ Donecopride (100 nM)	78*	1	4
+ Donecopride (500 nM)	79*	1	5
+ Donecopride (1 μ M)	62*	2	5
+ Donepezil (1 μ M)	82*	2	5

* : p < 0.05 versus A β 1-42, determined by one-way ANOVA followed by a Fisher's LSD test.

10 An important loss of MAP-2 neurons was consecutive to the application of the A β peptide. Donepezil, used here as a positive control, was able to significantly protect neurons from death. Two doses of Donecopride (100 nM and 500 nM) exerted neuroprotective effects to a similar extent to Donepezil.

Neurite network

15

The effect of Donecopride on the neurite network of MAP-2 neurons in a primary culture of hippocampal neurons is shown in Table 2 below.

Table 2: MAP-2 neurite network (% of control)

	MAP-2 neurite network (% of control)		
	mean	sem	n
Control	100	2	6
+ A β 1-42 (20 μ M)	63	1	6
+ Donecopride (1 nM)	64	2	5
+ Donecopride (5 nM)	69	2	6
+ Donecopride (10 nM)	68	2	5
+ Donecopride (50 nM)	71*	3	5
+ Donecopride (100 nM)	73*	1	5
+ Donecopride (500 nM)	79*	3	6
+ Donecopride (1 μ M)	76*	2	6
+ Donepezil (1 μ M)	92*	3	5

* : p < 0.05 versus A β 1-42, determined by one-way ANOVA followed by a Fisher's LSD test.

20

Total neurite network was severely shrunk upon A β 1-42 injury. Donepezil has significantly preserved almost all the neurite network. Four doses of Donecopride (50 nM, 100 nM, 500 nM and 1 μ M) exerted also protective effects on the neurite network.

The neurite network is proportional to the number of neurons in the culture. The total neurite network was normalized by the number of neurons, in order to determine the average length of neurite per neurons. The corresponding results are shown in Table 3 below.

Table 3: Neurite network / MAP-2 neurons (% of control)

	Neurite network / MAP-2 neurons (% of control)		
	mean	sem	n
Control	100	6	6
+ A β 1-42 (20 μ M)	90	3	6
+ Donecopride (1 nM)	90	3	4
+ Donecopride (5 nM)	99	2	6
+ Donecopride (10 nM)	96	3	4
+ Donecopride (50 nM)	91	5	4
+ Donecopride (100 nM)	93	1	4
+ Donecopride (500 nM)	100	4	5
+ Donecopride (1 μ M)	124*	5	5
+ Donepezil (1 μ M)	113*	4	4

* : p < 0.05 versus A β 1-42, determined by one-way ANOVA followed by a Fisher's LSD test.

This adjustment showed that neurite length per neuron was longer in presence of Donepezil and Donecopride (1 μ M), suggesting that these two compounds had an effect on neurite outgrowth.

Tau phosphorylation

The effect of Donecopride on the phosphorylation of Tau (AT100) in MAP-2 neurons in a primary culture of hippocampal neurons is shown in Table 4 below.

Table 4: Area of Tau (AT100)/neurons (% of control)

	Area of Tau (AT100)/neurons (% of control)		
	mean	sem	n
Control	100	4	5
+ A β 1-42 (20 μ M)	200	11	5
+ Donecopride (1 nM)	204	7	4
+ Donecopride (5 nM)	201	8	5
+ Donecopride (10 nM)	175	11	4
+ Donecopride (50 nM)	161*	12	5
+ Donecopride (100 nM)	154*	6	3
+ Donecopride (500 nM)	152*	8	4
+ Donecopride (1 μ M)	198	8	5
+ Donepezil (1 μ M)	151*	6	4

* : $p < 0.05$ versus A β 1-42, determined by one-way ANOVA followed by a Fisher's LSD test.

An hyperphosphorylation of Tau (on AT100) was observed under application of A β 1-42. Donepezil was able to significantly mitigate this hyperphosphorylation. Similarly, Donecopride (50 nM, 100 nM, 500 nM) has significantly reduced the hyperphosphorylation of Tau on a dose-dependent manner.

Effects of Donecopride on synapses in a primary culture of hippocampal neurons

To assess the formation of synapses, the distribution of PSD-95, a post-synaptic marker, and synaptophysin, a pre-synaptic marker, was studied. A structure positive for both PSD-95 and synaptophysin staining was considered as a synapse.

The effect of Donecopride on these synapses is shown in Table 5 below.

Table 5: Number of synapses (% of control)

	Number of synapses (% of control)		
	mean	sem	n
Control	100*	6	5
+ A β 1-42 (20 μ M)	67	4	6
+ Donecopride (1 nM)	69	5	4
+ Donecopride (5 nM)	83*	3	5
+ Donecopride (10 nM)	87*	7	5
+ Donecopride (50 nM)	91*	3	6
+ Donecopride (100 nM)	93*	3	4
+ Donecopride (500 nM)	94*	5	4
+ Donepezil (1 μ M)	85*	4	5
+ Donepezil (1 μ M)	88*	6	5

* : $p < 0.05$ versus A β 1-42, determined by one-way ANOVA followed by a Fisher's LSD test.

The stress resulting from the application of A β 1-42 caused a reduction in the number of synapses (as previously shown by Callizot *et al.* (2013) *J. Neurosci. Res.* 91:706-716).

Donepezil mitigated the loss of synapses. Similarly, Donecopride was also able to preserve the number of synapses, on a dose dependent manner (from 5 nM to 1 μ M). Interestingly, this effect was observed a low dose of the compound (5 nM). This effect increased with the dose.

Due to the injury caused by the A β 1-42 peptide, the number of neurons was reduced in the experimental conditions, which led to a reduction in the number of synapses. Therefore, to estimate the number of synapses per neuron, the number of synapses was normalized by the number of neurons for the control, A β 1-42, Donecopride (500 nM, the condition showing the highest number of synapses), and Donepezil groups.

This adjustment showed that ONLY DONECOPRIDE significantly promoted the formation of new synapses while Donepezil had no effect.

Conclusion

5 The present study indicates that Donecopride has beneficial effects on the neuronal survival and neurite network of hippocampal neurons injured with A β 1-42 peptide, an *in vitro* model of Alzheimer disease.

Moreover, Donecopride was able to reduce the hyperphosphorylation of Tau on the site AT100 and was able to significantly stimulate the formation of new synapses.

10 The effects of Donecopride were greater than those of Donepezil, suggesting that this compound is an interesting drug candidate as neuroprotective agent, in particular for treating neurodegenerative diseases.

15 Example 2

The present example demonstrates that the compounds of the invention can improve cognitive performances of mice in an AD/s *in vivo* model.

For that purpose, the efficacy of two compounds (Donecopride fumarate and Flucopride fumarate) was investigated using wild-type C57Bl6/J mice challenged with an
20 intracerebroventricular injection of A β 1-42 oligomers (A β O).

Compounds were dosed per os (through oral gavage) at three different doses. Cognitive performances were assessed using the Y-maze test, the Novel Object Recognition assay and the Morris-water maze test. At the end of the cognitive trials, all animals were sacrificed, blood and brain sampled for further ex-vivo analyses.

25

Schematic representation of the experiment

Briefly, 144 C57Bl6/J male mice (3 months of age) were received and housed (4 to 5 per cage) in quarantine during 7 days, or longer. Test items were dosed per os (through oral gavage) once daily at different concentrations from day -1 to day +17.

30 At day 0, mice received a single icv injection of vehicle or A β O.

At day +4 (i.e. four days after disease induction), spatial working memory was assessed using the Y-maze test.

From days +3 to days +14, learning capacities and long-term memory were investigated in the MWM assay.

35 At days +15/+16, recognition memory was investigated using the Novel Object recognition test (NOR).

Animals were sacrificed at day +17 and tissues prepared for further ex-vivo analyses.

Description of the experimental groups

5 The study involved a total of 144 mice divided in 12 experimental groups with 12 mice per experimental group. All animals received a single (and unilateral) icv injection of vehicle or A β O in a total volume of 1 μ L.

The different experimental groups are defined as follow:

- **GROUP A (vehicle CTRL):** po vehicle AND icv injection of vehicle (n = 12)
- 10 • **GROUP B (A β O CTRL):** po vehicle AND icv injection of A β O (n = 12)
- **GROUP C (positive CTRL):** po Donepezil subchronic AND icv injection of A β O (n = 12)
- **GROUP D (Donecopride CTRL):** po Donecopride (9 mg/kg) AND icv injection of vehicle (n = 12)
- 15 • **GROUP E (Flucopride CTRL):** po Flucopride (9 mg/kg) AND icv injection of vehicle (n = 12)
- **GROUP F (Donecopride Treated):** po Donecopride (1 mg/kg) AND icv injection of A β O (n = 12)
- **GROUP G (Donecopride Treated):** po Donecopride (3 mg/kg) AND icv injection of A β O (n = 12)
- 20 • **GROUP H (Donecopride Treated):** po Donecopride (9 mg/kg) AND icv injection of A β O (n = 12)
- **GROUP I (Flucopride Treated):** po Flucopride (1 mg/kg) AND icv injection of A β O (n = 12)
- **GROUP J (Flucopride Treated):** po Flucopride (3 mg/kg) AND icv injection of A β O (n = 25 12)
- **GROUP K (Flucopride Treated):** po Flucopride (9 mg/kg) AND icv injection of A β O (n = 12)
- **GROUP L (positive CTRL):** ip Donepezil acute on test days AND icv injection of A β O (n = 12)

30 Because a maximum of 24 mice could be icv injected per day, the study was performed in six independent runs. Two mice from all groups were included in each run.

Experimental procedures

Animal housing

35 Reception of 144 C57Bl6/J male (from Janvier, France) mice (3 months of age). Upon receipt, animals were placed in quarantine for a period of 7 days, or longer.

Mice were housed at standard temperature ($22 \pm 2^\circ\text{C}$) and in a light- and humidity-controlled environment (lights on from 8 am to 8 pm; humidity $55 \pm 10\%$) with ad libitum access to food and water. Mice were group housed and monitored twice-a-day by laboratory personnel (8 am and 4 pm). In case of 2 or more significant problems of the general health status, the affected mouse was sacrificed. Definitions of unacceptable health status are as follow: no spontaneous movements and inability to drink or feed during a 24-h observation period, more than 12 % weight loss, massive bleeding, spontaneous inflammation (general observations of mouse skin and eyes), or missing anatomy.

Over the entire procedure mice were weighted 3 times (i.e. before treatment and at days +8 and +17).

Compound storage, formulation and dosing

For per os dosing, Donecopride and Flucopride were formulated by solubilization in 0.9% NaCl. Compound dosing (total volume of 200 μL) started one day before induction of the disease (through icv injection of A β O) and was done for 19 consecutive days.

Stereotaxic injection

Single intra-cerebroventricular injection of 144 mice with vehicle or A β O (max. 24 mice per day, all mice randomized): under anesthesia (ip injection of a mixture of ketamine/xylazine at a dose of 110 and 15 mg/kg, respectively) A β O (1 μL), or vehicle (1 μL) were injected into the right lateral ventricle. Injections were made using 10 μL Hamilton micro syringes fitted with a 26-gauge needle. The procedure was terminated by a subcutaneous injection of metacam (analgesia) at a dose of 5 mg/kg. Animals were then placed individually in their home-cage and the cage was placed in a heated cabinet until the animal has fully recovered. Animals were carefully monitored to control recovery after anesthesia.

Preparation of A β O: A β 1-42 was obtained from Bachem (ref H1368) (batch number: 1052301). The preparation of stable A β 1-42 oligomers was performed as described in Garcia *et al.* (2010) *J. Neurosci.* **30**:7516-7527. The oligomeric preparation (identified as Batch#2016-14) contained a mixture of stable trimers and tetramers of A β 1-42, as well as monomeric forms of the peptide. All oligomer preparations used were previously characterized in terms of oligomer composition and *in vitro* neurotoxicity.

Cognition test, Y-maze test

6 independent trials involving each 24 mice (i.e. 2 mice from each experimental group) for a total of 144 mice at day +4 - Behavioral tests were performed 1 h after dosing.

This test assesses spatial working memory which is mainly mediated by the prefrontal cortex (working memory) and the hippocampus (spatial component). See Yoon *et al.* (2008) *Learn Mem.* **15**:97-105 and Spellman *et al.* (2015) *Nature* **522**:309-314 for the different components.

Prefrontal cortex mediates working memory in rodent, primates and human.

The measurement of spontaneous alternation behavior has been widely used by behavioral pharmacologists to assess spatial working memory, a component of short-term memory. In its simplest form, spontaneous alternation behavior comprises the tendency of mice to alternate their conventional non reinforced choice of arms on successive opportunities.

This test has been successfully implemented using icv infusion of A β O to induce cognitive deficits (Garcia *et al.* (2010) *J. Neurosci.* **30**:7516-7527).

Detailed protocol: Immediate spatial working memory performance was assessed by recording spontaneous alternation behavior in a Y-maze. The maze is made of opaque Plexiglas and each of the three arms is 40 cm long, 14 cm high, 10 cm wide and positioned at equal angles. The apparatus is placed in a homogeneously lit test room to obtain 12-15 lux in all arms as well as in the central zone. Mice are placed in the middle of one arm and allowed to explore the maze freely during 5 min session. The series of arm entries are video recorded (Smart v3.0 software, Bioseb) and an arm entry is considered complete when the hind paws of the mouse are completely placed in the arm. Alternation is defined as successive entries into the 3 arms on overlapping triplet sets. The percentage of alternation is calculated as the ratio of actual total alternations to possible alternations, defined as the number of arm entries minus 2, multiplied by 100. Locomotor activity is also recorded and evaluated during this phase (e.g. motivational index) by monitoring average speed and total distance.

Data analysis: Graphpad/Prism computer software is used for the statistical analyses. A non-parametric analysis of variance (Kruskal Wallis test) was carried out followed by non-parametric Mann-Whitney U tests to compare between groups. Values with $p < 0.05$ are considered statistically significant. Data are presented as mean $\pm$ SEM.

Cognition testing, NOR assay

6 independent trials involving each 24 mice (i.e. 2 mice from each experimental group) for a total of 144 mice at day +4 - Behavioral tests were performed 1 h after dosing.

This test assesses recognition memory for items and its human equivalent is the visual pairwise-comparison (VPC) (Wallace *et al.* (2015) *Handb. Exp. Pharmacol.* **228**:27-57). Recognition for object is mediated by the perirhinal cortex in rodents (Albasser *et al.* (2009) *Behav. Neurosci.* **123**:115-124), primates (Zeamer *et al.* (2015) *Dev. Cogn. Neurosci.* **11**:31-41) and humans (Watson & Lee (2013) *J. Neurosci.* **33**:4192-4200).

It was previously demonstrated that intra-cerebro-ventricular injection of A β O to mice leads to an impairment in novel object recognition task and is reversible with the acetylcholine esterase inhibitor donepezil and showed protective effect with human in a cytoprotective and neuroprotective mitochondrial-derived peptide.

Detailed protocol: One day before the cognitive test (i.e. at day +15), mice are habituated during a 10 minutes' trial during which they are placed in an empty open field. The day of the cognitive test (i.e. day +16), animals are placed in the same open field and are allowed to explore freely two identical objects for a trial of five minutes (acquisition trial). Then the animals are returned in their home-cage for an inter-trial time of five minutes. During the retention trial, animals are allowed to explore two different objects: one familiar and one novel object. During this time, the experimenter, blind to the treatment, record the time the mouse is actively exploring each object. All trials are video recorded (Smart v3.0 software, Bioseb). A discrimination index is then generated: Discrimination index = (time exploring novel object – time exploring familiar object) / total exploration time.

Data analysis: Graphpad/Prism computer software is used for the statistical analyses. A non-parametric analysis of variance (Kruskal Wallis test) is carried out followed by non-parametric Mann-Whitney U tests in order to compare between groups. Values of $p < 0.05$ are considered statistically significant. Data are presented as mean $\pm$ SEM.

Cognition testing, MWM assay

6 independent trials involving each 24 mice (i.e. 2 mice from each experimental group) for a total of 144 mice at day +4.

Spatial reference memory is a process, which tests the ability to remember the spatial cues to identify a location. It is mediated by the hippocampus in rodents (Broadbent *et al.* (2006) *Learn Mem.* **13**:187-191) and in human (Bartsch *et al.* (2010) *Science* **328**:1412-1415) using a virtual water-maze task. This test also involves a learning component.

Injection of A β O icv in mice induces a deficit in spatial reference memory in the Morris Water Maze (Garcia *et al.* (2010) *J. Neurosci.* **30**:7516-7527).

Detailed protocol: Habituation trials (visible platform) - The Morris water maze (MWM) was performed as described in Garcia *et al.* (2010) *J. Neurosci.* **30**:7516-7527. The experimental apparatus consists of a circular water tank (diameter = 100 cm; height = 50 cm) containing water at 21°C to a depth of 25 cm and rendered opaque to block the view past the water surface by adding an aqueous acrylic emulsion. A platform (diameter = 10 cm) is used and placed at the midpoint of a quadrant. The pool is located in a test room, homogeneously illuminated at 100 lux. The swimming path of the animals is recorded using a video tracking system. Mice are brought to the experimental room for at least 30 min prior to testing, to enable acclimation to the experimental room conditions. Navigation to a visible platform is carried out before place-navigation, to evaluate visual and motor abilities of all mice. Mice are submitted to 4 trials of 60 s per day (during 2 consecutive days), with an inter-trial interval of at least 1 h. Once mice have found the platform, they are left alone on the platform for an additional time of 30 s. There are no additional cues in the room. The platform position and starting points are randomly distributed over all 4 quadrants of the pool. Mice that fail to find the platform after 60 s are guided to its location and placed on the platform for 30 s.

Memory-acquisition trials (learning trials with hidden platform) - They are performed during 5 consecutive days and used to reach a steady state of escape latency. Mice are brought to the experimental room for at least 30 min prior to testing, to enable acclimation to the experimental room conditions. The hidden platform is submerged 1 cm below the water surface and placed at the midpoint of one quadrant. The pool is located in a test room homogeneously illuminated at 100 lux and containing various prominent visual cues. The swimming paths, swimming distance, swimming speed and thigmotaxis are recorded using a video tracking system. Mice are submitted to 4 trials of 60 s per day, with an inter-trial interval of at least 1 h. The mice are allowed to swim freely for 60 s, left alone for an additional 30 s on the hidden platform and then returned to their home cage during the inter-trial interval. Start positions (set at the border of quadrants) are randomly selected for each animal. In each trial, the time required to escape onto the hidden platform is recorded. Mice that fail to find the platform after 60 s are guided to and placed onto the platform for 30 s, before they are returned to their home cage.

Memory-retention trials (probe trials, no platform) – They are performed two days after the last training session. Mice are again acclimated to the experimental room for at least 30 min prior to testing. The platform is removed and each animal is allowed a free 60 sec swim. During the trial, the time spent in the target quadrant, the time spent in the quadrant opposite, and the crossings over the former platform location are measured and monitored by video tracking.

Data analysis: Graphpad/Prism computer software is used for the statistical analyses. A non-parametric analysis of variance (Kruskal Wallis test) is carried out followed by non-parametric Mann-Whitney U tests in order to compare between groups. Values of $p < 0.05$ are considered statistically significant. Data are presented as mean $\pm$ SEM.

Tissue sampling

Mice were sacrificed on day +17.

Blood sample collection: under anesthesia, mice are bled out. Approximately 600 μ L of whole blood was taken from the vena cava with a 1 mL syringe. Blood was collected in BD Microtainer K2E tubes (ref. 365975) or Sarstedt LiHe microtubes (ref. 41.1503.005). The tubes were gently inverted and samples placed on ice. Microtainers were centrifuged for 5 min at 4°C, 8600 g. Approximately 250 μ L plasma were transferred in Eppendorf tubes and frozen at -80°C for further analyses.

Brain sample collection: following blood collection, mice were intra-cardiac flash-perfused with 0.9% saline. The whole brain was removed and hemispheres were separated. The contralateral left hemisphere was flash-frozen in liquid nitrogen and stored at -80°C for further analysis (i.e. compound exposure). The ipsilateral right hemisphere was used to isolate hippocampus, pre-frontal cortex, and cortex. All brain structures were isolated on cooled support and flash-frozen in liquid nitrogen.

Results

Effects of the compounds of the invention on spatial working memory

To determine the effect of Donecopride and Flucopride on spatial working memory of mice, a Y-maze test was performed four days after icv injection of either vehicle or A β O. During the 5 min trial animals were allowed to explore the Y-maze device and alternation behavior was scored as described in the Experimental Procedures.

Mice from the vehicle control group (Group A) exhibited normal behavior in the exploration of the Y-maze with an alternation behavior of 68.0 ± 3.0 %. These results are in agreement with previous observations of similar control groups (see Garcia *et al.* (2010) *J. Neurosci.* **30**:7516-7527).

As expected, a single icv injection of A β O (Group B) resulted in a significant impairment ($p=0.0026$) of the cognitive performances in the Y-maze test when compared to vehicle control mice, with only 54.0 ± 2.0 % alternations.

Positive control mice, dosed per os with Donepezil and icv injected with A β O (Group C) were indistinguishable from control mice (alternation behavior of 66.1 ± 1.8 %)

and statistically different ($p=0.0011$) from A β O-injected mice. Positive control mice, dosed ip (acutely) with donepezil and icv injected with A β O (Group L) were statistically different from control mice ($p=0.0278$; alternation behavior of 60.8 ± 1.9 %) and also statistically different ($p=0.0421$) from A β O-injected mice.

5 Mice dosed with Donecopride (9 mg/kg/day) and icv injected with vehicle (Group D) exhibited an alternation behavior of 59.3 ± 4.0 %, not different from control mice ($p=0.2640$) and not different from A β O-injected mice ($p=0.5371$).

Mice dosed with Flucopride (9 mg/kg/day) and icv injected with vehicle (Group E) exhibited an alternation behavior of 63.1 ± 2.3 %, not different from control mice
10 ($p=0.1166$) and different from A β O-injected mice ($p=0.0111$).

Mice were dosed with increasing doses of Donecopride (1, 3 and 9 mg/kg/day) and were icv injected with A β O (Groups F, G and H, respectively). At a dose of 3 mg/kg/day, Donecopride inhibited A β O-induced impairment of spatial working memory. Indeed, mice from Group G exhibited an alternation behavior of 65.5 ± 4.4 %, not different from control
15 mice ($p=0.5543$) and different from A β O-injected mice ($p=0.0137$). At a dose of 1 mg/kg/day, Donecopride had no effect on A β O-induced impairment of spatial working memory as these mice exhibited an alternation behavior of 56.6 ± 3.7 %, different from control mice ($p=0.0488$) and not different from A β O-injected mice ($p=0.6859$). Due to a higher heterogeneity, mice from Group H (dosed with Donecopride at 9 mg/kg/day)
20 exhibited an intermediate phenotype with an alternation behavior of 64.3 ± 5.1 %, not different from control mice ($p=0.5994$) and also not different from A β O-injected mice ($p=0.1316$).

Mice were dosed with increasing doses of Flucopride (1, 3 and 9 mg/kg/day) and were icv injected with A β O (Groups I, J and K, respectively). At doses of 1 and 3
25 mg/kg/day, Flucopride inhibited A β O-induced impairment of spatial working memory. Indeed, mice from Groups I and J exhibited an alternation behavior of 67.1 ± 2.7 % and 65.3 ± 4.1 %, respectively, not different from control mice ($p=0.9754$ and $p=0.6936$, for groups I and J, respectively) and different from A β O-injected mice ($p=0.0029$ and $p=0.0454$, for groups I and J, respectively). In contrast, at a dose of 9 mg/kg/day,
30 Flucopride failed to protect mice from A β O-induced impairment of spatial working memory. Indeed, mice from Group K exhibited an alternation behavior of 59.1 ± 3.0 %, different from control mice ($p=0.0290$) but not different from A β O-injected mice ($p=0.2346$).

Effects of the compounds of the invention on learning capacities and long-term memory

To determine the effect of the compounds of the invention on learning capacities and long-term memory, a MWM test was performed from day +3 to day +14 after icv injection of either vehicle or A β O.

5 Habituation trials

In a first step (habituation trials performed at Days +3 and +4 after icv infusion of vehicle or A β O) mice were trained to escape from the water to a visible platform in the absence of other visual cues. During these trials, escape latency, swimming distance and swimming speed were recorded. There was no significant difference between groups in escape latency. No difference in swimming speed or swimming distance was detected.

Altogether, these data suggest that treatment did not affect the physical capacity nor the motivation of mice to escape from water.

Learning trials

The learning capacities of mice was monitored during five consecutive days (from day +7 to day +11 after icv infusion of vehicle or A β O). Animals performed 4 trials per day and were trained to localize a hidden platform using visual cues. During these learning trials, escape latency, swimming distance and swimming speed were recorded.

There was no statistically significant difference in the mean escape latency between groups at the beginning of the trials. All groups then appeared to exhibit some degree of learning.

Mice from the vehicle control group (Group A) learned efficiently the platform localization, and after five days of training (day 5), they exhibited a mean escape latency of 11.7 ± 1.5 s ($p=0.00031$ as compared to day 1). In contrast, the A β O-injected mice (Group B) exhibited an impaired behavior resulting in a mean escape latency of 17.3 ± 2.0 s after five days of training ($p=0.4537$, not different from day 1 and $p=0.00293$, significantly different from control mice).

Mice dosed sub-chronically with donepezil (po) and icv injected with A β O (Group C) learned efficiently the platform localization. After five days of training (day 5), they exhibited a mean escape latency of 14.7 ± 1.9 s ($p=0.09593$ as compared to day 1). At day 5, their performances were not different from control mice ($p=0.2188$) and not different from A β O-injected mice ($p=0.3477$).

Mice dosed acutely (on the test day) with donepezil (ip) and icv injected with A β O (Group L) learned efficiently the platform localization. After five days of training (day 5), they exhibited a mean escape latency of 13.4 ± 1.5 s ($p=0.01573$ as compared to day 1). At day 5, their performances were not different from control mice ($p=0.4187$) and not different from A β O-injected mice ($p=0.1272$).

Mice dosed with Donecopride (9 mg/kg/day) or Flucopride (9 mg/kg/day) and icv injected with vehicle (Groups D and E, respectively) exhibited normal cognitive performances. After five days of training (day 5), mice dosed with Donecopride exhibited a mean escape latency of 13.0 ± 1.7 s ($p=0.01778$ as compared to day 1). At day 5, their performances were not different from control mice ($p=0.5476$) and not different from A β O-injected mice ($p=0.10731$). After five days of training (day 5), mice dosed with Flucopride exhibited a mean escape latency of 16.3 ± 2.0 s ($p=0.04439$ as compared to day 1). At day 5, their performances were (for unknown reasons) different from control mice ($p=0.06709$) and not different from A β O-injected mice ($p=0.7235$). It is worthy to note that at day 4, Flucopride exhibited a mean escape latency of 14.2 ± 1.9 s, not different from control mice ($p=0.7933$) and not different from A β O-injected mice ($p=0.1225$).

Mice were dosed with increasing doses of Donecopride and icv injected with A β O (Groups F, G and H). The presence of Donecopride (at a dose of 3 mg/kg/day) resulted in an improvement of learning capacities of mice as compared with A β O-injected mice. Indeed, mice from group G exhibited a mean escape latency of 12.7 ± 1.5 s ($p=0.02933$ as compared to day 1) after five days of training. Their performances were not different from control mice ($p=0.6284$) but different from A β O-injected mice ($p=0.07381$).

Mice were dosed with increasing doses of Flucopride and icv injected with A β O (Groups I, J and K). The presence of Flucopride (at a dose of 1 and 3 mg/kg/day) resulted in an improvement of learning capacities of mice as compared with A β O-injected mice, whereas the compound at a dose of 9 mg/kg/day had no effect. Mice dosed with Flucopride at 1 mg/kg/day exhibited a mean escape latency of 13.1 ± 1.1 s ($p=0.03759$ as compared to day 1) after five days of training. Their performances were not different from control mice ($p=0.4367$) but different from A β O-injected mice ($p=0.07422$). Similarly, mice dosed with Flucopride at 3 mg/kg/day exhibited a mean escape latency of 12.5 ± 1.1 s ($p=0.00146$ as compared to day 1) after five days of training. Their performances were not different from control mice ($p=0.6477$) but different from A β O-injected mice ($p=0.04328$).

Probe trials

Long-term memory performance was determined four days after the last training session and 14 days after icv injection of vehicle or A β O. The platform was removed and each animal was allowed a free 60 sec swim. During the probe trial, the time spent in various quadrants of the pool, the number of crossings over the former platform location and the time at first cross (i.e. latency to target) were determined. During the probe trial, no difference in swimming speed was observed between the groups, showing normal physical capability and motivation.

Number of crossings - Mice from the vehicle control group (Group A) exhibited normal behavior with a mean crossing number of 5.3 ± 0.6 (Figure 3). These results are in agreement with previous observations of similar control groups. As expected, a single icv injection of A β O (Group B) resulted in a significant impairment of the cognitive performance when compared to vehicle control mice, with a decreased mean crossing number of 2.2 ± 0.4 ($p=0.0010$ as compared to control mice).

Mice dosed sub-chronically with donepezil (po) and icv injected with A β O (Group C) exhibited an improved behavior with a mean crossing number of 3.7 ± 0.4 . These mice were not different from vehicle control mice ($p=0.0502$) and significantly different from A β O injected mice ($p=0.0214$). Similarly, mice dosed acutely (on the test day) with donepezil (ip) and icv injected with A β O (Group L) exhibited an improved behavior with a mean crossing number of 3.8 ± 0.4 . These mice were not different from vehicle control mice ($p=0.0857$) and significantly different from A β O injected mice ($p=0.0159$).

Mice dosed with Donecopride (9 mg/kg/day) or Flucopride (9 mg/kg/day) in the presence of vehicle (Groups D and E, respectively) exhibited normal cognitive performances with a mean crossing number of 4.6 ± 0.5 and 4.6 ± 0.7 . These mice were not different from vehicle control mice ($p=0.4003$ and $p=0.3945$ for Donecopride and Flucopride, respectively) and significantly different from A β O injected mice ($p=0.0026$ and $p=0.0077$ for Donecopride and Flucopride, respectively).

Mice were dosed with increasing doses of Donecopride and icv injected with A β O (Groups F, G and H). The presence of Donecopride (at all doses) resulted in an inhibition of A β O-induced impairment of long-term memory evaluated using the number of crossings. The maximum effect was reached for a dose of 3 mg/kg/day (Group G). Indeed, these mice exhibited normal behavior with a mean crossing number of 5.1 ± 0.6 , not different from vehicle control mice ($p=0.6575$) and significantly different from A β O injected mice ($p=0.0018$).

Mice were dosed with increasing doses of Flucopride and icv injected with A β O (Groups I, J and K). The presence of Flucopride (at all doses) resulted in an inhibition of A β O-induced impairment of long-term memory evaluated using the number of crossings. The maximum effect was reached for a dose of 3 mg/kg/day (Group J). Indeed, these mice exhibited normal behavior with a mean crossing number of 4.1 ± 0.6 , not different from vehicle control mice ($p=0.1668$) and significantly different from A β O injected mice ($p=0.0242$).

Latency to target - Mice from the vehicle control group (Group A) exhibited normal behavior with a mean latency to target of 12.0 ± 1.9 s. These results are in agreement

with previous observations of similar control groups. As expected, a single icv injection of A β O (Group B) resulted in a significant impairment of the cognitive performance when compared to vehicle control mice, with an increased mean latency to target of 24.4 ± 4.7 s ($p=0.0074$ as compared to control mice).

5 Mice dosed sub-chronically with donepezil (po) and icv injected with A β O (Group C) exhibited an improved behavior with a mean latency to target of 14.6 ± 2.7 s. These mice were not different from vehicle control mice ($p=0.6860$) and significantly different from A β O injected mice ($p=0.0272$). Similarly, mice dosed acutely (on the test day) with donepezil (ip) and icv injected with A β O (Group L) exhibited an improved behavior with a
10 mean latency to target of 13.3 ± 2.3 s. These mice were not different from vehicle control mice ($p=0.9264$) and significantly different from A β O injected mice ($p=0.0028$).

Mice dosed with Donecopride (9 mg/kg/day) or Flucopride (9 mg/kg/day) in the presence of vehicle (Groups D and E, respectively) were found to exhibit normal cognitive performances with a mean latency to target of 7.2 ± 1.5 s and 12.0 ± 2.1 s. These mice
15 were not different from vehicle control mice ($p=0.0524$ and $p=0.7582$ for Donecopride and Flucopride, respectively) and significantly different from A β O injected mice ($p=0.0017$ and $p=0.0082$ for Donecopride and Flucopride, respectively).

Mice were dosed with increasing doses of Donecopride and icv injected with A β O (Groups F, G and H). The presence of Donecopride (at all doses) resulted in an inhibition
20 of A β O-induced impairment of long-term memory evaluated using the latency to target. The maximum effect was reached for a dose of 1 mg/kg/day (Group F). Indeed, these mice exhibited normal behavior with a mean latency to target of 9.3 ± 1.4 s, not different from vehicle control mice ($p=0.2548$) and significantly different from A β O injected mice ($p=0.0005$).

25 Mice were dosed with increasing doses of Flucopride and icv injected with A β O (Groups I, J and K). The presence of Flucopride (only at a dose of 9 mg/kg) resulted in an inhibition of A β O-induced impairment of long-term memory evaluated using the latency to target. Indeed, mice from Group K exhibited normal behavior with a mean latency to target of 10.7 ± 1.9 s, not different from vehicle control mice ($p=0.6891$) and significantly different
30 from A β O injected mice ($p=0.0031$).

Time in quadrant - Mice from the vehicle control group (Group A) spent significantly more time in the target quadrant ($p<0.0001$ as compared to time spent in the opposite quadrant). These results are in agreement with previous observations of similar
35 control groups. As expected, a single icv injection of A β O (Group B) resulted in a significant impairment of the cognitive performance when compared to vehicle control

mice, with more time spent in the opposite quadrant than in the target quadrant ($p=0.0779$ when times spent in target vs opposite quadrant are compared). The subchronic or acute dosing of donepezil (Groups C and L) failed to improve A β O-induced impairment of long-term memory using the time spent in the different quadrants as a read-out. Similarly, Donecopride and Flucopride did not improve quadrant frequentation during the probe test.

Effects of the compounds of the invention on recognition memory

To determine the effect of test items on recognition memory, a NOR test was performed 16 days after icv injection of either vehicle or A β O. Behavioral trials were performed as described in the Experimental Procedures.

Mice from the vehicle control group (Group A) exhibited normal behavior with a mean discrimination index of 0.35 ± 0.04 . These results are in agreement with previous observations of similar control groups. As expected, a single icv injection of A β O (Group B) resulted in a significant impairment ($p<0.0001$) of the cognitive performance when compared to vehicle control mice; with a mean discrimination index of -0.01 ± 0.03 , A β O-injected mice were not able to discriminate between novel and familiar objects.

Mice dosed sub-chronically with Donepezil (po) and icv injected with A β O (Group C) exhibited normal behavior with a mean discrimination index of 0.29 ± 0.09 . These mice were not different from vehicle control mice ($p=0.7439$) and significantly different from A β O injected mice ($p=0.0192$).

Mice dosed acutely (on the test day) with Donepezil (ip) and icv injected with A β O (Group L) exhibited normal behavior with a mean discrimination index of 0.30 ± 0.07 . These mice were not different from vehicle control mice ($p=0.9158$) and significantly different from A β O injected mice ($p=0.0030$).

Mice dosed with Donecopride (9 mg/kg/day) or Flucopride (9 mg/kg/day) in the presence of vehicle (Groups D and E, respectively) were found to exhibit normal cognitive performances with a mean discrimination index of 0.29 ± 0.04 and 0.36 ± 0.06 . These mice were not different from vehicle control mice ($p=0.3071$ and $p=0.8205$ for Donecopride and Flucopride, respectively) and significantly different from A β O injected mice ($p=0.0007$ and $p=0.0003$ for Donecopride and Flucopride, respectively).

Mice were dosed with increasing doses of Donecopride and icv injected with A β O (Groups F, G and H). The presence of Donecopride (at all doses) resulted in a dose-dependent inhibition of A β O-induced impairment of recognition memory. The maximum effect was reached for a dose of 9 mg/kg/day (Group H). Indeed, these mice exhibited normal behavior with a mean discrimination index of 0.43 ± 0.06 , not different from vehicle control mice ($p=0.3440$) and significantly different from A β O injected mice ($p=0.0003$).

Mice were dosed with increasing doses of Flucopride and icv injected with A β O (Groups I, J and K). The presence of Flucopride (at all doses) resulted in a dose-dependent inhibition (bell-shaped curve) of A β O-induced impairment of recognition memory. The maximum effect was reached for a dose of 3 mg/kg/day (Group J). Indeed, these mice exhibited normal behavior with a mean discrimination index of 0.46 ± 0.05 , not different from vehicle control mice ($p=0.1039$) and significantly different from A β O injected mice ($p=0.0003$).

Conclusion

Altogether, these data strongly suggest that both Donecopride and Flucopride improved cognitive performances of mice challenged with A β O.

Example 3

This example shows the anti-amnesic, anti-amyloid and anti-inflammatory effects of Donecopride and Flucopride in chronic administration to the 5XFAD mouse model of Alzheimer's disease.

Study rationale

The objective of the study was to evaluate the potential anti-amnesic, anti-amyloid and anti-inflammatory effect of Donecopride and Flucopride in chronic administration in a mouse model of Alzheimer's disease.

The mouse model used was the 5XFAD strain (referred at the Jackson Laboratory as "B6SJL-Tg(APP^{Sw}FILon,PSEN1*^{M146L}*^{L286V})6799Vas/Mmjax", MMRRC Stock No: 34840-JAX or "B6.Cg-Tg(APP^{Sw}FILon,PSEN1*^{M146L}*^{L286V})6799Vas/ Mmjax, MMRRC Stock No: 34848-JAX).

These 5XFAD transgenic mice overexpress mutant human APP(695) with the Swedish (K670N, M671L), Florida (I716V), and London (V717I) Familial Alzheimer's Disease (FAD) mutations along with human PS1 harboring two FAD mutations, M146L and L286V. Both transgenes are regulated by the mouse Thy1 promoter to drive overexpression in the brain. 5XFAD mice recapitulate major features of Alzheimer's Disease amyloid pathology and are a useful model of intraneuronal A β 42 induced neurodegeneration and amyloid plaque formation.

Methods and Experimental Design

Mice

Animal experiments were carried out in accordance with the Directive by the Council of the European Communities of November 24, 1986 (86/609/EEC). All efforts were made to minimize animal suffering and to reduce the number of mice used. The generation of 5XFAD mice was described in Oakley *et al.* (2006) *J. Neurosci.* **26**:10129-10140. These transgenic mice overexpress both human APP (695) harboring the Swedish (K670N, M671L), Florida (I716V) and London (V717I) familial AD (FAD) mutations and human Presenilin 1 (PS1) harboring the two FAD mutations M146L and L286V. Expression of both transgenes is regulated by neuronal-specific elements of the mouse *Thy1* promoter. The 5XFAD strain (B6/SJL genetic background) was maintained by crossing hemizygous transgenic mice with B6/SJL F1 breeders. The 5XFAD strain (C57BL/6J genetic background) was maintained by crossing hemizygous transgenic mice with C57BL/6J F1 breeders. All animals were genotyped by PCR using tail genomic DNA. Transgenic and WT mice were bred in our animal facility, had access to food and water *ad libitum* and were housed under a 12 h light-dark cycle at 22–24°C. Female 5XFAD mice were used in this study. For each experiment, the age of mice is indicated in months (with a two-week range).

Drugs

Donecopride (Donecopride fumarate, MR 31155) and Flucopride (Flucopride fumarate, MR 31193) were synthesized in the CERMN, Caen, France.

RS 67333 (1-(4-amino-5-chloro-2-methoxy-phenyl)-3-(1-butyl-4-piperidiny)-1-propanone), was used as a reference 5-HT₄ receptor agonist and was purchased from Tocris Bioscience (R&D Systems Europe, Lille, France).

Compounds were resuspended in DMSO (37.5 µg/µl, stored at -20°C) and freshly diluted 1:250 in 0.9% NaCl prior administration. Vehicle solution (0.9% NaCl, 0.4% DMSO) was used as control.

Animal treatments

5XFAD mice received chronic treatments with drugs or vehicle according to 2 different protocols. In each experiment, drugs or vehicle solution were administered i.p. twice a week (1 mg/kg). In "Protocol 1", mice (n = 6-7 mice per group) were treated with compounds for two months, from 2 to 4 months of age. In "Protocol 2", mice (n = 7) were treated with compounds for three months, from 1 month to 4 months of age. At the end of each protocol, mice were anesthetized with a mixture of 100 mg/kg ketamine and 10

mg/kg xylazine in saline solution and perfused transcardially with PBS. Brains were quickly isolated on ice, the olfactory bulbs and cerebellum removed and the two hemispheres divided. One hemisphere was frozen on dry ice and stored at -80°C for biochemical analysis, while the other was post-fixed in 4 % PFA for immunohistochemistry (IHC).

Cerebrospinal fluid (CSF) collection

Mice were anesthetized and mounted onto a stereotaxic instrument. The neck skin was cut and subcutaneous tissue and muscles separated with the help of micro-retractors (Fine Science Tools, Heidelberg, Germany). Mice were then laid down so that the head formed an angle of about 135° with the body (Liu and Duff (2008) *J. Vis. Exp.* **10**:960). A capillary tube (Borosilicate glass, B100-75-10, Sutter Instruments, Novato, California, USA) was used to punch the *dura mater* of the *cisterna magna*. CSF was collected by capillary action and transferred to 0.5 mL microtubes, immediately frozen on dry ice and stored at -80°C until use. Once thawed, samples were heated at 60°C for 5 min as described in the international application WO 2008/009868 and analyzed without further freezing-thawing cycles.

Brain extract preparation

Brain hemispheres, frontal cortex and hippocampus of 5XFAD mice and controls were thawed, weighed and homogenized in 4 volumes of tris-saline (50 mM Tris-HCl pH = 7.4, 150 mM NaCl) with a protease inhibitor cocktail (Roche Applied Science, Meylan, France). The resulting homogenates were centrifuged at 54,000 x g for 20 minutes and supernatants (the "soluble fraction") collected and aliquoted for storage at -80°C. Pellets were resuspended by brief sonication in 10 volumes of 6 M guanidine HCl in 50 mM Tris-HCl, pH = 7.6 and centrifuged again at 26,500 x g for 20 minutes. Supernatants (the "insoluble fraction") were aliquoted and stored at -80°C (Morishima-Kawashima *et al.* (2000) *Am. J. Pathol.* **157**:2093-2099).

Quantification of A β ₄₀ and A β ₄₂

ELISA kits from IBL International (Hamburg, Germany) for the dosage of A β ₄₀ (human amyloid β (1-40) assay kit, #27713) or A β ₄₂ (human amyloid β (1-42) assay kit, #27719) were used according to the manufacturer's instructions. Reactions were read at 620 nm and 450 nm using an Infinite 2000 luminescence counter. The obtained values were normalized to the protein concentration of each sample, measured using a BCA protein assay (Sigma-Aldrich).

Immunohistochemistry

Thirty-micrometer-thick sections were cut using a vibratome (Microm HM 650V, Thermo Scientific, Saint Herblain, France) and stored in cryoprotectant medium at -20°C.

5 For the labeling of amyloid plaques, free-floating tissue sections of frontal cortex, hippocampus and entorhinal cortex (coordinates from the bregma: frontal cortex = 1.98 mm, hippocampus = -1.94 mm, entorhinal cortex = -3.08 mm) were extensively washed in PBS and then incubated in blocking solution (PBS; 3% BSA; 0.1% Triton X-100) for 1 h. Sections were stained with Hoechst dye (1:1000, Life Technologies, Saint Aubin, France)

10 for 15 minutes to detect cell nuclei and then with freshly prepared thioflavin T solution (#T3516-5G, Sigma-Aldrich) (final concentration: 0.01 mg/ml in blocking buffer) for 15 minutes. After washing in 70 % ethanol for 5 minutes, samples were mounted on poly-lysine slides with coverslips. For GFAP (glial fibrillary acidic protein) staining, free-floating brain sections were blocked as before and incubated with polyclonal rabbit anti-GFAP

15 (1:1000, Z0334, Dako, Les Ullis, France) at 4°C overnight. After thioflavin T staining and washing with 70 % ethanol, the secondary Alexafluor 594 goat anti-rabbit antibody (1:1000, A11012, Life Technologies) was added for 2 h. PBS washes and mounting were performed as described before.

Image acquisition and analysis

20 Images were acquired with an AxioImager Z1 microscope (Carl Zeiss S.A.S., Marly le Roi, France). Analysis of thioflavin T staining was performed blindly and data are presented as the mean number of particles per mm² in two to three tissue sections from the same brain area/animal (Image J software). GFAP expression was quantified using

25 Image J software and results are expressed as area fractions.

Novel object recognition test

The cognitive performance of mice was tested using the novel object recognition (NOR) test (Bevins and Besheer (2006) *Nat. Protoc.* 1:1306-1311). Animals were

30 extensively handled during drug treatment prior to the test onset. Each day, mice were allowed to familiarize with the test room for at least 1 h prior to the test. Testing was carried out in a Plexiglas box (width: 35 cm, length: 20 cm, height: 20 cm) placed in a dimly lit room. On day 1 and 2, each mouse was habituated to the empty box for 10 min/day. On day 3, two objects (constructed out of plastic toys) were positioned in the

35 cage, 5 cm away from the opposing walls. During the training session, each animal was placed between the two objects, facing the wall and then was allowed to explore the

objects for 5 min. Mice were then returned to their home cage and 24 h later went through a 5 min test session in which one of the two (familiar) objects was replaced by a new one (novel). The whole experiment was video-recorded and object exploration [time spent by the mouse nose in contact with the object or by sniffing it at a distance ≤ 1 cm] was blindly measured. Two parameters were considered: 1) the exploration time (sec) spent by the animal interacting with the two familiar objects during the training session and 2) the exploration time spent by the animal interacting with the novel object relative to the total exploration time ($[\text{novel}/(\text{familiar} + \text{novel})] \times 100$) during the test. A discrimination index was also calculated ($[\text{novel} - \text{familiar}]/[\text{familiar} + \text{novel}]$).

Statistical analysis

All values are expressed as the mean $\pm$ SEM. Significant effects of treatments were determined by ANOVA analysis followed by Tukey's *post hoc* tests in the case of multiple comparison groups. In all other cases, the unpaired Student's *t* test was used. For all statistical tests, $P < 0.05$ was considered significant. Analysis was performed with GraphPad Prism 7 (GraphPad Software, La Jolla, CA).

Results

Effects of Donecopride and Flucopride on amyloid load in 5XFAD brains

27 female 5XFAD mice (B6/SJL genetic background) were used in this study. Mice received vehicle or compounds (1 mg / kg) i.p., twice a week for two months, from 2 to 4 months of age.

$A\beta_{40}$ and $A\beta_{42}$ were quantified from brain extract in soluble and insoluble fractions. Results are expressed in % of vehicle.

The results obtained are presented in table 6 below:

Table 6: $A\beta_{40}$ and $A\beta_{42}$ levels (% of controls)

	Soluble fraction			Insoluble fraction		
	$A\beta_{40}$	SEM	n	$A\beta_{40}$	SEM	n
Vehicle	100.00	11.38	7	100.00	14.56	7
Donecopride	110.18	10.68	7	79.97	6.40	7
Flucopride	110.51	16.67	7	97.16	10.43	7
	$A\beta_{42}$	SEM	n	$A\beta_{42}$	SEM	n
Vehicle	100.00	11.26	6	100.00	6.70	7
Donecopride	65.93*	8.36	7	67.85*	12.59	6
Flucopride	30.19****	8.04	7	73.16	4.62	7

*: $p < 0.05$ versus vehicle, determined by one-way ANOVA followed by a Tukey's test.

The values of the vehicle groups presented in Table 6 were as follows:

- soluble fraction:
 - $A\beta_{40} = 9.48 \pm 1.08 \mu\text{g}/\text{mg}$ of protein,
 - $A\beta_{42} = 0.24 \pm 0.03 \mu\text{g}/\text{mg}$ of protein;
- 5 ○ insoluble fraction:
 - $A\beta_{40} = 0.68 \pm 0.10 \mu\text{g}/\text{mg}$ of protein,
 - $A\beta_{42} = 10.84 \pm 0.73 \mu\text{g}/\text{mg}$ of protein.

Anti-amyloid effect. In the soluble fraction of 5XFAD mouse brains, the chronic
10 administration of Donecopride and Flucopride (1 mg/kg, twice a week) was able to
significantly reduce $A\beta_{42}$ levels (*p < 0.05 versus vehicle for Donecopride and ****p <
0.0001 versus vehicle for Flucopride, determined by one-way ANOVA followed by Tukey's
test) without any change on $A\beta_{40}$ levels. Similarly, in the insoluble fraction, donecopride
reduced $A\beta_{42}$ load in the mouse brains (*p < 0.05 versus vehicle, determined by one-way
15 ANOVA followed by Tukey's test). Insoluble $A\beta_{40}$ levels were unaffected by both drugs.

*Effects of Donecopride and Flucopride on memory, amyloid load in CSF, amyloid plaques
and astrogliosis in 5XFAD mice*

28 female 5XFAD mice (C57BL/6J genetic background) were used in this study.
20 Mice received vehicle or compounds (1 mg / kg) i.p., twice a week for three months, from
1 to 4 months of age.

At the end of the treatment, mice were evaluated for long-term memory
performance in novel object recognition test (NOR). The inter-session interval was 24
hours. As no mice failed to explore either of the two objects or explored both objects for
25 less than 10 sec during the training session, all the mice were included in the data
analysis.

Anti-amnesic effect. One-month-old 5XFAD females and WT littermates were
treated with RS 67333, vehicle, Donecopride or Flucopride (1 mg/kg, twice a week for 3
months) and then recognition memory was assessed with the novel object recognition
30 (NOR) test. Habituation sessions were started 3 days after the end of treatment to avoid
interference with acute effects. The interval between training session and test was of 24h.
Vehicle-treated mice presented impaired memory performance and were not able to
discriminate the novel object versus the familiar one, as shown by similar exploration time
and non-significant discrimination index. RS 67333-treatment reverses cognitive
35 impairment as indicated by the higher percentage of time devoted to the exploration of the

novel object in comparison to mice treated with vehicle (**p < 0.01 versus familiar object, determined by two-way ANOVA followed by a Sidak's test). Similarly, Donecopride and Flucopride chronic treatments were able to prevent memory alteration (**p < 0.01 versus familiar object for Donecopride, *p < 0.05 versus familiar object for Flucopride, determined by two-way ANOVA followed by a Sidak's test). Discrimination index of the 3 compound-treated groups were different from zero, the chance level (determined by unpaired Student's t test). The total exploration time during the training session did not differ significantly in the four groups, indicating that the recognition memory improvement in 5XFAD mice treated with Donecopride or Flucopride is not secondary to an increase of the exploratory activity.

Amyloid load in CSF. A β_{42} concentration in cerebrospinal fluid (CSF) of 5XFAD mice treated with RS 67333, Donecopride or Flucopride (1 mg/kg, twice a week for 3 months) was not significantly different compared to controls, indicating that chronic 5-HT₄ receptor stimulation did not affect amyloid levels in CSF (determined by one-way ANOVA followed by a Tukey's test).

Anti-amyloid effect. Frontal cortex, hippocampus and entorhinal cortex were analyzed as representative areas of 5XFAD mouse brain (frontal, median and caudal sections) and of human brain regions that are affected early by Alzheimer's disease and are highly enriched in amyloid deposits.

Donecopride treatment (1 mg/kg, twice a week for 3 months) significantly decreased the number of amyloid plaques compared to vehicle in frontal cortex (reduction of $16 \pm 3\%$, **p < 0.01 compared with vehicle) and in entorhinal cortex (reduction of $24 \pm 4\%$, **p < 0.01 compared with vehicle). A significant reduction of the plaque number was also observed in entorhinal cortex after Flucopride treatment (1 mg/kg, twice a week for 3 months) with a reduction of $28 \pm 6\%$, relative to control (**p < 0.01 compared with vehicle). No significant effect was seen following RS 67333-treatment (1 mg/kg, twice a week for 3 months) neither in frontal cortex nor in entorhinal cortex. Amyloid plaque number in hippocampus of 5XFAD mice treated with RS 67333, Donecopride or Flucopride (1 mg/kg, twice a week for 3 months) was not significantly different compared to controls. Statistics were determined by one-way ANOVA followed by a Tukey's test.

Anti-inflammatory effect. Immunohistochemical assessment of astroglial (anti-GFAP antibody, Glial fibrillary acidic protein) showed that Donecopride and RS 67333 chronic treatments (1 mg/kg, twice a week for 3 months) significantly reduced astrogliosis ($54 \pm 10\%$ and $62 \pm 6\%$ decrease of GFAP staining in entorhinal brain slices of treated animals in comparison to controls that received vehicle, respectively, *p < 0.01 compared with vehicle). In entorhinal cortex, Flucopride treatment (1 mg/kg, twice a week for 3

months) induced a reduction of 51 ± 5 % of GFAP staining that was close to significance ($p = 0.06$). However, GFAP staining in frontal cortex or hippocampus of 5XFAD mice treated with RS 67333, Donecopride or Flucopride (1 mg/kg, twice a week for 3 months) was not significantly different compared to controls. Statistics were determined by one-way ANOVA followed by a Tukey's test.

Conclusion

The study demonstrates that Donecopride and Flucopride exert anti-amyloid effects (reduction of $A\beta_{42}$ levels and amyloid plaque) and anti-inflammatory effects (reduction of astrogliosis) upon chronic administration to 5XFAD mice, a transgenic mouse model of Alzheimer's disease. These effects are mostly prominent in entorhinal cortex and frontal cortex. Moreover, chronic administration of Donecopride and Flucopride is able to exert an anti-amnesic effect and to prevent the appearance of memory deficits in 5XFAD mice.

All these effects are comparable, and sometimes greater, to those of RS 67333 (5-HT₄ receptor agonist chosen as reference), pointing out Donecopride and Flucopride as promising drug against Alzheimer's disease.

Example 4

This example discloses the neuroprotective effect of multiple compounds of general formula (I) as defined above on hippocampus neurons intoxicated with amyloid peptide oligomers.

Material and methods

Primary culture of hippocampal neurons

Rat hippocampal neurons were cultured as described by Callizot *et al.* (2013) *J. Neurosci. Res.* **91**:706-716. Briefly, pregnant female rats of 17 days gestation (Rats Wistar; Janvier Labs France) were killed using a deep anesthesia with CO₂ chamber and a cervical dislocation. Then, fetuses were removed from the uterus and immediately placed in ice-cold L15 Leibovitz medium with a 2% penicillin (10,000 U/ml) and streptomycin (10 mg/ml) solution (PS) and 1% bovine serum albumin (BSA). The hippocampi were treated for 20 min at 37°C with a trypsin- EDTA solution at a final concentration of 0.05% trypsin and 0.02% EDTA. The dissociation was stopped by addition of Dulbecco's modified Eagle's medium (DMEM) with 4.5 g/l of glucose, containing DNase I grade II (final concentration 0.5 mg/ml) and 10% fetal calf serum

(FCS). Cells were mechanically dissociated by three forced passages through the tip of a 10-ml pipette.

Cells were then centrifuged at 515 x g for 10 min at 4°C. The supernatant was discarded, and the pellet was resuspended in a defined culture medium consisting of Neurobasal medium with a 2% solution of B27 supplement, 2 mmol/l L-glutamine, 2% PS solution, and 10 ng/ml brain-derived neurotrophic factor (BDNF). Viable cells were counted in a Neubauer cytometer, using the trypan blue exclusion test. Cells were seeded at a density of 20,000 per well in 96-well plates pre-coated with poly-L-lysine and were cultured at 37°C in an air (95%) - CO₂ (5%) incubator.

The medium was changed every 2 days. For 96 well-plates, only 60 wells were used. The wells of first and last lines and columns were not used (to avoid any edge effect) and were filled with sterile water.

Test compounds and human A β ₁₋₄₂ exposure

Test compounds: The following compounds were tested:

- MR31193
- MR31176
- MR31192, and
- MR33583

Pre-incubation: On day 17 of culture, the compounds were dissolved in the culture medium and pre-incubated with primary hippocampal neurons for 1 hour, before A β ₁₋₄₂ exposure.

Injury: The hippocampal neurons were exposed with A β solutions (see below) after 17 days of culture. The A β ₁₋₄₂ preparation was done following the procedure described by Callizot *et al.* (2013) *J. Neurosci. Res.* **91**:706-716. The batch number of the A β ₁₋₄₂ used in this study contains 10% of oligomers (quantification by WB as performed in Combes *et al.* (2015) *J. Neurosci. Res.* **93**:633-643). Briefly, A β ₁₋₄₂ peptide was dissolved in the defined culture medium mentioned above, at an initial concentration of 40 μ mol/l. This solution was gently agitated for 3 days at 37°C in the dark and immediately used after being properly diluted in culture medium to the concentrations used (20 μ mol/l or 2.5 μ mol/l corresponding to 2 μ mol/l or 0.25 μ mol/l of oligomers (A β O) respectively). A β ₁₋₄₂ preparation was added to a final concentration of 20 or 2.5 μ mol/l (respectively 2 μ mol/l or 0.25 μ mol/l of A β O, determined by automatic WB) diluted in control medium in presence of the compounds.

End-point evaluation

24 hours after intoxication, the supernatants were taken off and were immediately frozen for future analytical analysis. They were kept at -20°C for up to 6 months. Then, the hippocampal neurons were fixed by a cold solution of ethanol (95%) and acetic acid (5%) for 5 min at -20°C. They were washed twice again in PBS, and were then permeabilized and the non-specific sites blocked using a solution of PBS containing 0.1% of saponin and 1% of FCS, for 15 min at room temperature.

Immunostaining: MAP-2 / AT100 - After fixation and permeabilization, cells were incubated for 2 hours with:

- a chicken polyclonal antibody anti microtubule-associated-protein 2 (MAP-2) at dilution of 1/1000 in PBS containing 1% fetal calf serum and 0.1% saponin (this antibody stains specifically cell bodies and neurites, allowing study of neuronal cell death and neurite network); and
- a mouse monoclonal antibody anti-phospho Tau (AT100) at dilution of 1/100 in PBS containing 1% fetal calf serum and 0.1% saponin.

These antibodies were revealed with Alexa Fluor 488 goat anti mouse IgG and Alexa Fluor 568 goat anti-chicken IgG at the dilution 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.

For each condition, 30 pictures (representative of the whole well area) per well were taken using ImageXpress® (Molecular Devices) with 20x magnification. All images were generated using the same acquisition parameters. From images, analyses were directly and automatically performed by Custom Module Editor® (Molecular Devices). The following read-outs were investigated:

- Total number of neurons (neuron survival, number of MAP-2 positive neurons)
- Neurite network (in μm of MAP-2 positive neurons)
- Area of AT100 (μm^2 , overlapping with MAP-2 positive neurons).

Immunostaining: PSD95 and SYN - After fixation and permeabilization, cells were incubated for 2 hours with:

- mouse monoclonal antibody anti post synaptic density 95kDa (PSD95) at dilution of 1/200 in PBS containing 1% fetal calf serum and 0.1% saponin;
- rabbit polyclonal antibody anti-synaptophysin (SYN) at the dilution of 1/100 in PBS containing 1% fetal calf serum and 0.1% saponin.

These antibodies were revealed with Alexa Fluor 488 goat anti mouse IgG and Alexa Fluor 568 goat anti-rabbit IgG at the dilution 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.

For each condition, 40 pictures per well were taken using ImageXpress (Molecular Devices) with 40x magnification. All images were taken with the same conditions. Synapses evaluation were performed automatically by using Custom module editor® (Molecular Devices). The following endpoints were assessed:

- 5 - Number of synapses (overlapping between PSD95/SYN)

Statistical analysis

All values are expressed as mean +/- SEM (standard error of the mean). Statistical analysis was performed by one-way ANOVA, followed by a Dunnett's or a LSD Fisher's test. p<0.05 was considered significant.

10

Results

The following results were obtained.

- 15 - MR31193 shows a strong neuroprotective effect (survival, neurite and synaptic network). As can be seen in Figures 1 and 2, the effect follows a bell shaped curve with a maximum effect observed at a concentration of 100 nM for survival and neurite network (Figures 1A-C). The maximal effect on the synapse network was obtained at lower concentrations (between 5 nM and 100 nM, Figure 2). A significant effect on Tau hyperphosphorylation was also observed, with a maximal effect at 50 nM (see Figure 1D).
- 20 - As can be seen in Figures 3 and 4, MR31176 shows a neuroprotective effect at high concentrations (survival, neurite and synaptic network. A significant effect on Tau hyperphosphorylation was also observed at high concentration (see Figure 3D).
- 25 - As can be seen in Figures 5 and 6, MR31192 shows a very strong neuroprotective effect at very low doses (for example 1-5 nM for survival, see Figure 5A). A very large effect was also observed on neurite network at every tested dose (see Figure 5B). This compound even showed a neurotrophic effect (it induced neuritic growth), as can be seen on Figure 5C. The number of synapses was also increased at low doses (1-5 nM, see Figure 6). An important effect was also observed on Tau hyperphosphorylation (see Figure 5D).
- 30 - A neuroprotective effect following a bell shaped curved was also observed with MR33583 (see Figures 7 and 8). The active concentrations were above 50-500 nM. A strong effect on neurite network was observed at almost every tested dose (see Figure 7B). A bell-shaped effect was also observed on Tau hyperphosphorylation with a maximal effect at 50-100 nM (see Figure 7D).
- 35

These results confirm that all tested compounds of general formula (I) are neuroprotective agents, the compounds MR31193, MR31192 and MR33583 being particularly efficient.

Example 5

This example shows the neuroprotective effects of the compounds MR31192, and MR36014.

Material and methods

Primary culture of hippocampal neurons

Rat hippocampal neurons were cultured as described by Callizot *et al.* (2013) *J. Neurosci. Res.* **91**:706-716. Briefly, pregnant female rats of 17 days gestation (Rats Wistar; Janvier Labs France) were killed using a deep anesthesia with CO₂ chamber and a cervical dislocation. Then, fetuses were removed from the uterus and immediately placed in ice-cold L15 Leibovitz medium with a 2% penicillin (10,000 U/ml) and streptomycin (10 mg/ml) solution (PS) and 1% bovine serum albumin (BSA). The hippocampi were treated for 20 min at 37°C with a trypsin- EDTA solution at a final concentration of 0.05% trypsin and 0.02% EDTA. The dissociation was stopped by addition of Dulbecco's modified Eagle's medium (DMEM) with 4.5 g/l of glucose, containing DNase I grade II (final concentration 0.5 mg/ml) and 10% fetal calf serum (FCS). Cells were mechanically dissociated by three forced passages through the tip of a 10-ml pipette.

Cells were then centrifuged at 515 x g for 10 min at 4°C. The supernatant was discarded, and the pellet was resuspended in a defined culture medium consisting of Neurobasal medium with a 2% solution of B27 supplement, 2 mmol/l L-glutamine, 2% PS solution, and 10 ng/ml brain-derived neurotrophic factor (BDNF). Viable cells were counted in a Neubauer cytometer, using the trypan blue exclusion test. Cells were seeded at a density of 20,000 per well in 96-well plates pre-coated with poly-L-lysine and were cultured at 37°C in an air (95%) - CO₂ (5%) incubator.

The medium was changed every 2 days. For 96 well-plates, only 60 wells were used. The wells of first and last lines and columns were not used (to avoid any edge effect) and were filled with sterile water.

Test compounds and human A β ₁₋₄₂ exposure

Test compounds: The following compounds were tested:

- MR31192,
- MR36014, and
- Donepezil

Pre-incubation: On day 17 of culture, the compounds were dissolved in the culture medium and pre-incubated with primary hippocampal neurons for 1 hour, before A β ₁₋₄₂ exposure.

Injury: The hippocampal neurons were exposed with A β solutions (see below) after 17 days of culture. The A β ₁₋₄₂ preparation was done following the procedure described by Callizot *et al.* (2013) *J. Neurosci. Res.* **91**:706-716. The batch number of the A β ₁₋₄₂ used in this study contains 10% of oligomers (quantification by WB as performed in Combes *et al.* (2015) *J. Neurosci. Res.* **93**:633-643). Briefly, A β ₁₋₄₂ peptide was dissolved in the defined culture medium mentioned above, at an initial concentration of 40 μ mol/l. This solution was gently agitated for 3 days at 37°C in the dark and immediately used after being properly diluted in culture medium to the concentrations used (20 μ mol/l or 2.5 μ mol/l corresponding to 2 μ mol/l or 0.25 μ mol/l of oligomers (A β O) respectively). A β ₁₋₄₂ preparation was added to a final concentration of 20 or 2.5 μ mol/l (respectively 2 μ mol/l or 0.25 μ mol/l of A β O, determined by automatic WB) diluted in control medium in presence of the compounds.

End-point evaluation

24 hours after intoxication, the supernatants were taken off and were immediately frozen for future analytical analysis. They were kept at -20°C for up to 6 months. Then, the hippocampal neurons were fixed by a cold solution of ethanol (95%) and acetic acid (5%) for 5 min at -20°C. They were washed twice again in PBS, and were then permeabilized and the non-specific sites blocked using a solution of PBS containing 0.1% of saponin and 1% of FCS, for 15 min at room temperature.

Immunostaining: MAP-2 / AT100 - After fixation and permeabilization, cells were incubated for 2 hours with:

- a chicken polyclonal antibody anti microtubule-associated-protein 2 (MAP-2) at dilution of 1/1000 in PBS containing 1% fetal calf serum and 0.1% saponin (this antibody stains specifically cell bodies and neurites, allowing study of neuronal cell death and neurite network); and
- a mouse monoclonal antibody anti-phospho Tau (AT100) at dilution of 1/100 in PBS containing 1% fetal calf serum and 0.1% saponin.

These antibodies were revealed with Alexa Fluor 488 goat anti mouse IgG and Alexa Fluor 568 goat anti-chicken IgG at the dilution 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.

For each condition, 30 pictures (representative of the whole well area) per well were taken using ImageXpress® (Molecular Devices) with 20x magnification. All images were generated using the same acquisition parameters. From images, analyses were directly and automatically performed by Custom Module Editor® (Molecular Devices). The following read-outs were investigated:

- Total number of neurons (neuron survival, number of MAP-2 positive neurons)
- Neurite network (in μm of MAP-2 positive neurons)
- Area of AT100 (μm^2 , overlapping with MAP-2 positive neurons).

Immunostaining: PSD95 and SYN - After fixation and permeabilization, cells were incubated for 2 hours with:

- mouse monoclonal antibody anti post synaptic density 95kDa (PSD95) at dilution of 1/200 in PBS containing 1% fetal calf serum and 0.1% saponin;
- rabbit polyclonal antibody anti-synaptophysin (SYN) at the dilution of 1/100 in PBS containing 1% fetal calf serum and 0.1% saponin.

These antibodies were revealed with Alexa Fluor 488 goat anti mouse IgG and Alexa Fluor 568 goat anti-rabbit IgG at the dilution 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.

For each condition, 40 pictures per well were taken using ImageXpress (Molecular Devices) with 40x magnification. All images were taken with the same conditions. Synapses evaluation were performed automatically by using Custom module editor® (Molecular Devices). The following endpoints were assessed:

- Number of synapses (overlapping between PSD95/SYN)

Statistical analysis

All values are expressed as mean $\pm$ SEM (standard error of the mean). Statistical analysis was performed by one-way ANOVA, followed by a Dunnett's or a LSD Fisher's test. $p < 0.05$ was considered significant.

Results

As can be seen on Figures 9 and 10, the compound MR31192 is active up to a concentration of 500 pM (survival and neurite network, see Figure 9A,B,C) and a

significant reduction of Tau hyperphosphorylation (see Figure 9D) is also observed at 100 pM. A neuroprotective effect on synapses is further observed at 500 pM (see Figure 10). Accordingly, the compound MR31192 is efficient at very low doses, in particular at doses inferior to 100 nM (between 100 pM and 500 pM). At these very low doses, the MR31192 shows a neuroprotective effect similar to the one observed with Donepezil but at 1 μ M.

As can be seen on Figures 11 and 12, the compound MR36014 (fluorine analog of MR31192) displays a neuroprotective profile similar to the one obtained with MR31192 at nM doses. A neuroprotective effect was also observed at pM doses. This effect is particularly significant for survival and neurite network (see Figure 11A, B,C) and for Tau hyperphosphorylation (see Figure 11D). The effect on synapses is significant up to a concentration of 50 pM (see Figure 12). At these very low doses, the MR36014 shows a neuroprotective effect almost equivalent to the one observed with Donepezil but at 1 μ M.

Accordingly, both compounds are active at very low doses (both at nM doses and at pM doses), which is particularly interesting for avoiding potential toxicity and/or side effects.

Example 6

This example shows the neuroprotective effects of MR36014 and MR33583 on dopaminergic TH-positive neurons injured with MPP⁺.

Parkinson's disease (PD) is a common neurodegenerative movement disorder that affects around 1 % of the population over the age of 70. It is the second most common neurodegenerative disease after Alzheimer's disease. The patients suffering from PD display symptoms of motor instabilities with resting tremor as the first symptom in 70 % of the cases. Other clinical symptoms are rigidity, bradykinesia and postural instability and often include cognitive impairment, depression and sleep disorders.

Although the pathological mechanisms leading to substantia nigra (SN) degeneration might be multiple, several pathways are considered to be central: protein aggregation linked to proteasomal impairments, mitochondrial dysfunction (also caused by specific DA-toxins), and impairment in dopamine (DA) release.

As confirmed by Dauer and Przedborski (2003) *Neuron* **39**:889-909, dopaminergic neurons-specific toxins (DA-toxins), in particular 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP, the prodrug of the neurotoxin MPP⁺), 6-hydroxydopamine (6-OHDA) or rotenone, cause parkinsonism in humans. These toxins are largely used by

scientists to experimentally mimic the pathology in animals. Any substances reducing DA-toxin neurotoxicity may be useful as a new therapeutic agent for the treatment or prevention of PD.

The aim of the present study was to investigate the neuroprotective effect of MR36014 and MR33583 (at 4 concentrations) on dopaminergic TH-positive neurons injured with MPP⁺. The test compounds were pre-incubated for 1 hour before MPP⁺ application (4 μ M for 48 h). The neuroprotective effect (survival and neurite network) of test compounds was investigated. In addition, the effect on the cytoplasmic alpha-synuclein accumulation was studied.

Materials and method

Primary culture of mesencephalic neurons

All experiments were carried out in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals and followed current European Union regulations (Directive 2010 / 63 / EU). Agreement number: A1301310.

Rat dopaminergic neurons were cultured as described by Callizot *et al.* (2019) *PLoS One* **14**:e0215277 and Visanji *et al.* (2008) *FASEB J.* **22**:2488-2497. Briefly, pregnant female rat (Wistar) of 15 days of gestation were killed using a deep anesthesia with CO₂ chamber and a cervical dislocation. The midbrains obtained from 15-day-old rat embryos (Janvier, France) were dissected under a microscope. The embryonic midbrains were removed and placed in ice-cold medium of Leibovitz (L15) containing 2% Penicillin-Streptomycin (PS) and 1% bovine serum albumin (BSA). The ventral portion of the mesencephalic flexure, a region of the developing brain rich in dopaminergic neurons, was used for the cell preparations.

Midbrains were dissociated by trypsinisation for 20 min at 37°C (solution at a final concentration of 0.05% trypsin and 0.02% EDTA). The reaction was stopped by the addition of Dulbecco's modified Eagle's medium (DMEM) containing DNAase I grade II (0.5 mg/ml) and 10% foetal calf serum (FCS). Cells were then mechanically dissociated by 3 passages through a 10 ml pipette. Then cells were centrifuged at 180 x g for 10 min at 4°C on a layer of BSA (3.5%) in L15 medium. The supernatant was discarded and the cell pellets were re-suspended in a defined culture medium consisting of Neurobasal supplemented with B27 (2%), L-glutamine (2 mM), 2% PS solution, 10 ng/ml Brain-derived neurotrophic factor (BDNF) and 1 ng/ml Glial-Derived Neurotrophic Factor (GDNF). Viable cells were counted in a Neubauer cytometer using the trypan blue exclusion test. The cells were seeded at a density of 40,000 cells/well in 96 well-plates (pre-coated with poly-L-lysine) and maintained in a humidified incubator at 37°C in 5%

CO₂ / 95% air atmosphere. Half of the medium was changed every 2 days with fresh medium.

Briefly, on day 6 of culture, the medium was removed, and fresh medium was added, with or without test compounds and with or without MPP⁺ for 48 hours diluted in control medium. 6 wells per condition were assessed.

Test compounds and MPP⁺ exposure

Pre-incubation: On day 6 of culture, the compounds were diluted in the culture medium and pre-incubated with primary dopaminergic neurons for 1 hour, before MPP⁺ exposure.

Injury: 1 hour after test compounds incubation, MPP⁺ was added to a final concentration of 4 μM, diluted in culture medium in the presence of compounds for 48 hours.

Organization of culture plates

Test compounds were tested in 96-well plate (n = 6 culture wells per condition). MR36014 and MR33583 were pre-incubated for 1 hour before MPP⁺ intoxication. The following conditions were assessed:

PLATE 1 (TH/α-syn)
Control (vehicle)
+ MPP ⁺ (4 μM, 48 h) / vehicle
+ MPP ⁺ (4 μM, 48 h) / MR36014 500 pM
+ MPP ⁺ (4 μM, 48 h) / MR36014 1 nM
+ MPP ⁺ (4 μM, 48 h) / MR36014 5 nM
+ MPP ⁺ (4 μM, 48 h) / MR36014 10 nM
+ MPP ⁺ (4 μM, 48 h) / MR33583 500 pM
+ MPP ⁺ (4 μM, 48 h) / MR33583 1 nM
+ MPP ⁺ (4 μM, 48 h) / MR33583 5 nM
+ MPP ⁺ (4 μM, 48 h) / MR33583 10 nM

End-point evaluation

After 48 hours of intoxication, the cell culture supernatants were taken off and were immediately frozen for future analysis. The cells were fixed by a solution of 4% paraformaldehyde in PBS, pH =7.3 for 20 min at room temperature. The cells were washed twice in PBS. Cell membrane permeabilization and blocking of non-specific sites were done using a solution of PBS containing 0.1% saponin and 1% FCS, for 15 min at room temperature.

Immunostaining: TH and α -syn - The cultures were incubated with:

- monoclonal anti-Tyrosine Hydroxylase (TH) antibody produced in mouse at a dilution of 1/10,000 in PBS containing 1% FCS, 0.1% saponin, for 2 hours at room temperature.
- 5 - polyclonal anti-alpha synuclein (α -syn) antibody produced in rabbit at a dilution of 1/200 in PBS containing 1% FCS, 0.1% saponin, for 2 hours at room temperature

These antibodies were revealed with Alexa Fluor 488 goat anti-mouse IgG at a dilution 1/800 and with Alexa Fluor 568 goat anti-rabbit IgG at a dilution 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 hour at room temperature.

10 **Automatic computer analysis** - For each condition, 20 pictures (representing the whole well area) are automatically taken using ImageXpress® (Molecular Devices) at 10x magnification (20 pictures) using the same acquisition parameters. From images, analyses were directly and automatically performed by Custom Module Editor® (Molecular Devices). The following read-outs were measured:

- 15 - Analysis of total number of TH neurons (TH positive neurons),
- total neurite network of TH positive neurons (in μm)
- α -syn aggregation (area of overlapping between TH and α -syn staining, in μm^2)

Statistical analysis

20 All values are expressed as mean $\pm$ SEM (standard error of the mean). Statistical analysis was performed by one-way ANOVA, followed by a Dunnett's or a LSD Fisher's test. $p < 0.05$ was considered significant.

Results

25 *Effect of MR36014 on the survival, neurite network and α -syn aggregation of TH neurons after injury with MPP⁺.*

Application of MPP⁺ induced a clear neurotoxicity on dopaminergic neurons, as observed by a reduced survival (Figure 13A), a loss of the neurite network (Figure 13B) and a pathological accumulation of α -syn (Figure 13C) as previously shown (Callizot *et al.* 30 (2019) *PLoS One* **14**:e0215277).

Application of MR36014 had a strong overall neuroprotective effect on TH neurons as this compound improved TH neuron survival (from 1 nM to 10 nM), protected their neurite network (all investigated doses) and reduced the accumulation of α -syn (all investigated doses).

Effect of MR33583 on the survival, neurite network and α -syn aggregation of TH neurons after injury with MPP⁺.

After MPP⁺ injury, MR33583 improved neuronal survival (100 nM, see Figure 14A) and partially protected the neurite network (from 10 nM to 100 nM, see Figure 14B).
5 Positive effect of MR33583 was also observed on the aggregation of α -syn (50 nM and 100 nM, see Figure 14C).

Discussion

10 The aim of the study was to investigate the neuroprotective effects of MR36014 and MR33583 in an *in vitro* model of Parkinson's disease.

This study shows that:

- both compounds counteract the toxicity of MPP⁺ on dopaminergic neurons,
- MR36014 is more potent than MR33583, as this compound showed a higher efficacy on promoting the survival of TH neurons.
- 15 - MR36014 was active at lower doses than MR33583.

Altogether, this study showed that MR36014 and MR33583 are interesting drug candidate for Parkinson's disease, and that MR36014 is more active than MR33583.

20

Example 7

This example discloses the evaluation of neuroprotective effects of compounds MR36014 and MR33583 on rat primary cortical neurons after glutamate injury.

25 The glutamatergic system, and in particular NMDA receptors (glutamatergic receptors) have a major role in the processes of learning and memory. Synaptic plasticity can be regulated by NMDA receptor signaling. However, an over-activation of NMDA receptors and glutamatergic excitotoxicity is a common pathological feature in neurodegenerative diseases (Lewerenz and Maher (2015) *Front Neurosci.* 9:469).

30 Glutamate excitotoxicity has been implicated in the acute neurological damage from ischemia and traumatic brain injury and in the chronic neurodegeneration in Alzheimer's disease (AD) and Huntington's disease (HD). Excitotoxic neuronal death via over-activation of NMDAR contributes to excessive flux of calcium (Ca²⁺) into the cell. This triggers a range of responses resulting in cell death, including increased oxidative stress,
35 inappropriate activation of proteases such as calpain, dysregulation of Ca²⁺-related pathways, mitochondrial damage and an apoptotic cascade.

In this view, an early pharmacological treatment with substances reducing the glutamate excitotoxicity, might represent a very good option for improving neuronal survival (and for improving cognition function), and might represent an interesting therapeutic strategy for patients diagnosed with Alzheimer's disease (Wang and Reddy (2017) *J. Alzheimers Dis.* **57**:1041-1048).

The present study assesses the neuroprotective effect of MR36014 and MR33583 (at 4 concentrations) in rat primary cortical neurons after glutamate injury. The test compounds were pre-incubated for 1 hour before glutamate application (20 μ M for 20 min). The neuroprotective effect (survival and neurite network) of test compounds were investigated.

Materials and method

Primary culture of cortical neurons

All experiments were carried out in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals and followed current European Union regulations (Directive 2010 / 63 / EU). Agreement number: A1301310.

Rat cortical neurons were cultured as described by Callizot *et al.* (2013) *J. Neurosci. Res.* **91**:706-716. Pregnant female rat (Wistar) of 15 days of gestation were killed using a deep anesthesia with CO₂ chamber and a cervical dislocation. Briefly, fetuses were collected and immediately placed in ice-cold L15 Leibovitz medium with a 2% penicillin (10,000 U/mL) and streptomycin (10 mg/mL) solution (PS) and 1% bovine serum albumin (BSA). Cortex were treated for 20 min at 37°C with a trypsin-EDTA solution at a final concentration of 0.05% trypsin and 0.02% EDTA. The dissociation was stopped by addition of Dulbecco's modified Eagle's medium (DMEM) with 4.5 g/l of glucose, containing DNase I grade II (final concentration 0.5 mg/ml) and 10% fetal calf serum (FCS). Cells were mechanically dissociated by three forced passages through the tip of a 10-ml pipette. Cells were then centrifuged at 515 x g for 10 min at 4 °C. The supernatant was discarded, and the pellet was resuspended in a defined culture medium consisting of Neurobasal medium with a 2% solution of B27 supplement, 2 mmol/l L-glutamine, 2% PS solution, and 10 ng/ml brain-derived neurotrophic factor (BDNF). Viable cells were counted in a Neubauer cytometer, using the trypan blue exclusion test.

The cells were seeded at a density of 25,000 per well in 96-well plates precoated with poly-L-lysine and were cultured at 37°C in an air (95%) - CO₂ (5%) incubator.

To avoid the edge effect, the first and last columns as well as first and last lines of the plate were not used in the study. Empty wells were filled with water.

The medium was changed every 2 days. The cortical neurons were injured with A β solutions (see below) after 11 days of culture.

Test compounds and glutamate exposure

5 **Pre-incubation:** On day 13 of culture, the compounds were dissolved in the culture medium and pre-incubated with primary cortical neurons for 1 hour, before glutamate exposure.

10 **Injury:** 1 hour after test compound incubation, glutamate was added to a final concentration of 20 μ M diluted in control medium still in presence of the test compounds for 20 min. After 20 min, glutamate was washed out and fresh culture medium with the test compounds were added for additional 48 hours.

Organization of culture plates

15 Test compounds were tested in 96-well plate (n= 6 culture wells per condition). The following conditions were assessed:

PLATE 1 (MAP-2)	
Control (vehicle)	
+ Glutamate (20 μ M, 20 min) / vehicle	
+ Glutamate (20 μ M, 20 min) / MR36014 500pM	
+ Glutamate (20 μ M, 20 min) / MR36014 1 nM	
+ Glutamate (20 μ M, 20 min) / MR36014 5 nM	
+ Glutamate (20 μ M, 20 min) / MR36014 10 nM	
+ Glutamate (20 μ M, 20 min) / MR33583 1 nM	
+ Glutamate (20 μ M, 20 min) / MR33583 10 nM	
+ Glutamate (20 μ M, 20 min) / MR33583 50 nM	
+ Glutamate (20 μ M, 20 min) / MR33583 100 nM	

End-point evaluation

20 **Immunostaining: MAP-2 (survival and neurite network)** - 48 hours after intoxication, the cell culture supernatant was taken off and was immediately frozen for future analysis. Cells were fixed by a cold solution of ethanol (95%) and acetic acid (5%) for 5 min at -20°C. Cells were washed twice in PBS. Cells were permeabilized and non-specific binding sites were blocked with a solution of PBS containing 0.1% saponin and 1% FCS for 15 min at room temperature.

25 The cultures were incubated for 2 h with a mouse monoclonal antibody anti-microtubule-associated-protein 2 (MAP-2), at a dilution of 1/400, in PBS containing 1% fetal calf serum and 0.1% saponin. This antibody was revealed with an Alexa Fluor 488 goat anti-mouse IgG (1/400 dilution) in PBS containing 1% FCS, 0.1% saponin, for 1 h at

room temperature. MAP-2 is a neuronal marker present in the cell bodies and neurites of neurons, which allow the study of neuronal survival and the length of the neurite network.

Automatic computer analysis - For each condition, 30 pictures (representative of the all well area) per well will be taken using ImageXpress® (Molecular Devices) with 20x magnification. All images will be generated using the same acquisition parameters. From images, analyses will be directly and automatically performed by Custom Module Editor® (Molecular Devices).

The following read-outs will be investigated:

- The total neuron survival (MAP-2 positive, number), (data will be expressed into mean number of neurons of 30 pictures per well).
- The total neurite network (MAP-2 in μm), (data will be expressed into mean of neurons of 30 pictures per well).

Statistical analysis

All values are expressed as mean $\pm$ SEM (standard error of the mean). Statistical analysis was performed by one-way ANOVA, followed by a Dunnett's or a LSD Fisher's test. $p < 0.05$ was considered significant.

Results

Effects of MR36014 and MR33583 on cortical neurons injured with glutamate

The glutamatergic injury induced a loss of cortical neurons (Figure 15A and 15C; 32% of neuronal death) and a shrinkage of the total neurite network (Figure 15B and 15D; 38% of neurite loss).

Neuronal survival. MR36014, added 1 h before glutamate and let for 48 h after glutamate application, significantly protected cortical neurons from death at 1 nM (see Figure 15A). Under the same experimental conditions, MR33583 did significantly protect cortical neurons from death at 50 nM and 100 nM (see Figure 15C).

Neurite network. All MR36014 tested concentrations (500 pM to 10 nM) significantly protected the neurite network, with a maximal effect at 1 nM (see Figure 15B). MR33583 significantly protected the neurite network from 1 nM to 100 nM. The effect followed a bell shape curve with a maximal effect at 50 nM (see Figure 15D).

Discussion

The aim of the study was to investigate the neuroprotective effects of MR36014 and MR33583 in an *in vitro* model of neuronal stress induced by glutamatergic

excitotoxicity. Glutamatergic stress is a pathological feature present in different neurological diseases, including Alzheimer's disease and cerebral ischemia.

In line with the results of the study, it can be concluded that:

- both compounds counteract the toxicity of glutamate on cortical neurons,
- 5 - MR36014 and MR33583 showed similar efficacy, although MR36014 was active at a lower dose (on neuronal survival).

Altogether, this study shows that MR36014 and MR33583 are interesting drug candidates for neurological diseases involving glutamatergic stress.

10

Example 8

This example discloses the evaluation of neuroprotective effects of MR36014 and MR33583 on rat primary cortical neurons after glutamate injury.

15

Amyotrophic lateral sclerosis (ALS) is a fatal disorder characterized by subtle onset of focal weakness, typically in the limbs but sometimes in bulbar muscles, which progresses to paralysis of almost all skeletal muscles. There is significant clinico-pathological and genetic overlap between ALS and frontotemporal lobar dementia (FTLD). In ALS, death from respiratory paralysis occurs typically within five years. The cellular

20 pathology is focal at onset and spreads in a pattern suggesting successive involvement of contiguous neuronal populations. Death of motoneurons occurs in conjunction with deposition of aggregated proteins in motoneurons and oligodendrocytes, and neuroinflammation.

25

The complex pathophysiology of ALS presents many potential therapeutic targets. Although, a wide range of agents has been investigated, only Riluzole (Rilutek®), an antiglutamatergic drug, has demonstrated consistent benefit, and it is the only approved drug for the treatment of the disease. However, Riluzole's benefits are modest - it prolongs survival of ALS patients for several months (~7%) with minimal effect on functional measures.

30

Although the precise molecular pathways that cause the death of motor neurons in ALS remain unknown, some possible mechanisms include a) glutamate-mediated excitotoxicity; b) decrease in neurotrophic factors (BDNF, GDNF...); c) mitochondrial alterations and oxidative damages; d) abnormalities in cytoskeletal proteins resulting in neuronal atrophy and death.

35

TDP-43 (Transactivating response element DNA binding protein 43 kDa) has been shown to accumulate in cytoplasm of motor neurons in most cases of ALS. TDP43 is a

nuclear RNA-binding protein involved in several aspects of RNA processing that actively shuttles between the nucleus and cytoplasm.

The aim of the present study was to evaluate the effects of MR36014 and MR33583 (at 4 concentrations), on primary spinal motor neuron (MN) after a glutamate injury.

Materials and method

Primary culture of spinal motor neurons

All experiments were carried out in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals and followed current European Union regulations (Directive 2010 / 63 / EU). Agreement number: A1301310.

Rat spinal cord motor neurons (MNs) were cultured as described by Martinou *et al.* (1992) *Neuron*. **8**:737-744 and Wang *et al.* (2013) *Hum. Mol. Genet.* **22**:4706-4719. Briefly, pregnant female rats of 14 days gestation (Rats Wistar; Janvier Labs France) were killed using a deep anesthesia with CO₂ chamber and a cervical dislocation. Then, fetuses were removed from the uterus and immediately placed in ice-cold L15 Leibovitz medium with a 2% penicillin (10,000 U/ml) and streptomycin (10 mg/ml) solution (PS) and 1% bovine serum albumin (BSA).

Spinal cords were treated for 20 min at 37°C with a trypsin-EDTA solution at a final concentration of 0.05% trypsin and 0.02% EDTA. The dissociation was stopped by addition of Dulbecco's modified Eagle's medium (DMEM) with 4.5 g/l glucose, containing DNase I grade II (final concentration 0.5 mg/ml) and 10% fetal calf serum (FCS). Cells were mechanically dissociated by three forced passages through the tip of a 10-ml pipette. Cells were then centrifuged at 515 x g for 10 min at 4°C. The supernatant was discarded, and the pellet was resuspended in a defined culture medium consisting of Neurobasal medium with a 2% solution of B27 supplement, 2 mmol/l L-glutamine, 2% PS solution, and 10 ng/ml brain-derived neurotrophic factor (BDNF). Viable cells were counted in a Neubauer cytometer, using the trypan blue exclusion test. Cells were seeded at a density of 20,000 per well in 96-well plates precoated with poly-L-lysine and were cultured at 37°C in an air (95%) - CO₂ (5%) incubator.

The medium was changed every 2 days. The wells of the first lines and columns were not used for culture (to avoid edge effect) and were filled with sterile water. The motor neurons were injured with glutamate after 13 days of culture.

Test compounds and glutamate exposure

Pre-incubation: On day 13 of culture, the compounds were dissolved in the culture medium and pre-incubated with primary cortical neurons for 1 h, before glutamate exposure.

5 **Glutamate injury:** On day 13 of culture, and after the 1 h of pre-incubation, glutamate was added to a final concentration of 5 μ M diluted in control medium still in presence of the compounds for 20 min. After 20 min, glutamate was washed out and fresh culture medium with the compounds were added for additional 24 h.

10 *Organization of culture plates*

Test compounds were tested in 96-well plate (n = 6 culture wells per condition).

The following conditions were assessed:

PLATE 1 (MAP-2 / TDP-43) motor neurons	
Control (vehicle)	
+ Glutamate (5 μ M, 20 min) / vehicle	
+ Glutamate (5 μ M, 20 min) / MR36014 (500 pM)	
+ Glutamate (5 μ M, 20 min) / MR36014 (1 nM)	
+ Glutamate (5 μ M, 20 min) / MR36014 (5 nM)	
+ Glutamate (5 μ M, 20 min) / MR36014 (10 nM)	
+ Glutamate (5 μ M, 20 min) / MR33583 (1 nM)	
+ Glutamate (5 μ M, 20 min) / MR33583 (10 nM)	
+ Glutamate (5 μ M, 20 min) / MR33583 (50 nM)	
+ Glutamate (5 μ M, 20 min) / MR33583 (10 nM)	

End-point evaluation

15 24 hours after intoxication, the supernatants were taken off and were immediately frozen for future analysis. The cells were fixed by a cold solution of ethanol (95%) and acetic acid (5%) for 5 min at -20°C. After permeabilization with 0.1% saponin, cells were incubated for 2 h with:

- a mouse monoclonal antibody anti microtubule-associated-protein 2 (MAP-2) at dilution of 1/400 in PBS containing 1% fetal calf serum and 0.1% saponin. This antibody was revealed with Alexa Fluor 488 goat anti-mouse IgG at the dilution 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.
- a rabbit polyclonal antibody anti-nuclear TAR DNA-binding protein 43 (TDP-43) at dilution of 1/100 in PBS containing 1% fetal calf serum and 0.1% saponin. The antibody TDP-43 was revealed with Alexa Fluor 568 goat anti-rabbit at a dilution of 1/400 in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.

25 For each condition, 30 pictures (representative of the whole well area) per well were automatically taken using ImageXpress® (Molecular Devices) with 20x

magnification, using the same acquisition parameters. From images, analyses were directly and automatically performed by Custom Module Editor® (Molecular Devices).

Endpoint analysis

5 The following endpoints were automatically assessed:

- Analysis of neuron survival (MAP-2 staining, number of neurons),
 - Analysis of neurite network (MAP-2 staining, total neurite length in μm),
 - Analysis of neurite network/neurons (neuronal network/number of MAP2 neurons),
 - Analysis of cytoplasmic TDP-43 in MAP-2 positive neurons (overlapping between
- 10 MAP-2 and cytoplasmic TDP-43 in μm^2).

Statistical analysis

All values are expressed as mean $\pm$ SEM (standard error of the mean). Statistical analysis was performed by one-way ANOVA, followed by a Fisher's LSD test. $p < 0.05$ was

15 considered significant.

Results

Effects of MR36014 in a primary culture of spinal motor neurons injured with glutamate

Neuronal survival. A loss of large MAP-2 spinal motor neurons followed the

20 application of glutamate (42% of neuronal death) (Figure 16A). At 500 pM and 1 nM, MR36014 significantly improved spinal motor neurons survival.

Neurite network. Neurite network was severely reduced upon glutamate injury (46% of neurite loss, Figure 16B). MR36014 significantly protected the neurite network at 500 pM and 1 nM. The length of the neurite network is proportional to the number of

25 neurons. The ratio "neurite network length" / "number of neurons" was calculated to estimate the average length of neurite per neurons. The ratio was not modified by MR36014 (Figure 16C).

Effects of MR33583 in a primary culture of spinal motor neurons injured with glutamate

30 **Neuronal survival.** As shown in figure 17, a loss of large MAP-2 spinal motor neurons followed the application of glutamate (Figure 17A). MR33583 (added 1 h before glutamate and let for 24 h after injury) exerted a dose-dependent neuroprotective effect (10 to 100 nM).

Neurite network. As shown in figure 17, neurite network was severely reduced

35 upon glutamate injury (Figure 17B). MR33583 significantly protected the neurite network

from 10 nM to 100 nM, on a dose dependent manner. The ratio was not modified by MR36014 (Figure 17C).

TDP43. At the highest dose, MR33583 (100 nM), reduced the signal of TDP43 in the cytoplasm of spinal motor neurons (Figure 17D).

5

Discussion

The aim of this study was to assess the neuroprotective effects of two compounds, MR36014 and MR33583, in an *in vitro* model of amyotrophic lateral sclerosis, based on a primary culture of spinal cord motor neurons injured with glutamate.

10

The results of this study indicate that:

- MR36014 provided clear neuroprotective effects at 500 pM and 1 nM, as it improved neuronal survival and protected the neurite network.
- MR33583 showed clear neuroprotective effects on all parameters (neuronal survival, preservation of the neurite network and accumulation of cytoplasmic TDP43).

15

Altogether, these results indicate that MR36014 and MR33583 were able to mediate neuroprotection on spinal cord motor neurons, and they are potential drug candidates for amyotrophic lateral sclerosis.

20

Example 9

This example shows the evaluation of neuroprotective effects of MR33583 on rat primary GABAergic neurons under a growth factor deprivation.

25

HD (Huntington's disease) is an autosomal dominant inherited neurodegenerative disease that affects approx. 4–10 in 10 000 in the Caucasian community. The HD brain is characterized by loss of the MSNs (medium spiny neurons) of the striatum, enlargement of the ventricles and a corresponding shrinkage of the overlying cortex. The GABAergic (γ -aminobutyric acid) cells are the most populous neuronal cell type of the striatum (90–95% in rats and over 85% in humans), along with several small populations of interneurons (Victorin (1992) *Prog. Neurobiol.* **38**:611-639). MSNs are characterized by their expression of GAD64 enzyme. They receive the bulk of inputs to the striatum, receiving afferents from the cortex, thalamus and midbrain, as well as being the major output neuron of the striatum, projecting to various regions of the CNS (central nervous system), including the globus pallidus and the substantia nigra. As such, they form complex

35

neuronal loops within the basal ganglia that are important for the control of action, cognition and emotion (Nakano *et al.* (2000) *J. Neurol.* **247** (suppl. 5):v1-v15).

The importance of growth factors and their decrease in the neurodegenerative diseases (such as AD, PD or HD) has been often raised as one of the multiple causes of these pathologies. Genetic as well as pharmacologic deprivation of BDNF or GDNF impairs learning and memory, and raised to neuronal death (Yamada *et al.* (2003) *J. Pharmacol. Sci.* **91**:267-270). The growth factor deprivation model has been characterized in several neuronal cell types, such as primary culture of rodent neurons (Atabay *et al.* (1996) *J. Neurosci. Res.* **43**:465-475), human SK-N-SH and SH-SY5Y neuroblastoma cells (Ba *et al.* (2003) *J. Neurosci. Methods* **123**:11-22; Russo *et al.* (2004) *Brain Res.* **1009**:40-53).

Under these growth factor-deprived conditions, the severe loss of viability is due to apoptotic cell death, detected by a significant up-regulation of apoptotic-associated parameters, including cleaved caspase-3, PARP and H2A.X. In addition, gene and protein expression of the anti-apoptotic Bcl-2 has been shown to be down-regulated, whereas those of the proapoptotic Bax were up-regulated. In addition, deprivation of brain-derived neurotrophic factor (BDNF) has been shown to trigger cell death pathways by activating caspases through increased p75NTR signaling (Yu *et al.* (2008) *J. Neurosci.* **28**:7467-7475).

Interestingly, *Bdnf*^{-/-} mice also show structure-specific neuroanatomical alterations and behavioral abnormalities. They display decreased dendritic complexity and spine density in the cortex and hippocampus and to an even greater extent in the striatum, where 90 % of the affected cells are GABAergic MSNs (Rauskolb *et al.* (2010) *J. Neurosci.* **30**:1739-1749).

The aim of this study was to investigate the neuroprotective effect of MR33583 (at 4 concentrations) in MSN of striatum survival after growth factor deprivation (BDNF and GDNF deprivation), an *in vitro* model of Huntington's disease.

Materials and method

Primary culture of GABAergic neurons

All experiments were carried out in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals and followed current European Union regulations (Directive 2010 / 63 / EU). Agreement number: A1301310.

Rat MSN of striatum were cultured as described by Ivkovic *et al.* (1999) *J. Neurosci.* **19**:5409-5419 and Schinelli *et al.* (1988) *J. Neurochem.* **50**:1900-1907. Briefly pregnant female rats of 15 days gestation were killed using a deep anesthesia with CO₂

chamber and a cervical dislocation. Fetuses were collected and immediately placed in ice-cold L15 Leibovitz medium with a 2% penicillin (10,000 U/ml) and streptomycin (10 mg/ml) solution (PS) and 1% bovine serum albumin (BSA). Only a restricted ventral portion of the mesencephalic flexure was used for cell preparation as this is the region of the developing brain rich in MSN cells. These areas were treated for 20 min at 37°C with a trypsin-EDTA solution at a final concentration of 0.05% trypsin and 0.02% EDTA. The dissociation was stopped by addition of Dulbecco's modified Eagle's medium (DMEM) with 4.5 g/l of glucose, containing DNase I grade II (final concentration 0.5 mg/ml) and 10% fetal calf serum (FCS). Cells were mechanically dissociated by three forced passages through the tip of a 10-ml pipette. Then, the cells were centrifuged at 180 x g for 10 min at room temperature on a layer of BSA (3.5%) in L15 medium. The supernatant was discarded, and the cell pellet was re-suspended in a defined culture medium consisting of Neurobasal supplemented with B27 (2%), L-glutamine (2 mM), 1% PS solution, BDNF (10 ng/ml) and GDNF (1 ng/ml). Viable cells were counted in a Neubauer cytometer using the trypan blue exclusion test. Cells were seeded at a density of 40,000 cells/well in 96 well-plates (wells were pre-coated with poly-L-lysine) and were cultured at 37°C in an air (95%) / CO₂ (5%) incubator.

To avoid any edge effect, the first and last columns as well as first and last lines of the plate were not used in the study. Empty wells were filled with water. The medium was changed every 2 days.

Test compounds and growth factor deprivation

Pre-incubation: On day 13 of culture, the test compound was diluted in the culture medium and pre-incubated with GABAergic neurons for 1 h before growth factor deprivation (BDNF and GDNF).

Growth factor deprivation: 1 h after incubation with test compound, half of the medium was changed with medium devoid of growth factors. The deprivation was applied for 96 hours.

Organization of culture plates

Test compounds were tested in 96-well plate (n = 6 culture wells per condition). The following conditions were assessed:

PLATE 1 (GAD67)
Control (vehicle)
+ Growth factor deprivation/ vehicle
+ Growth factor deprivation/ MR33583 (1 nM)
+ Growth factor deprivation/ MR33583 (10 nM)

+ Growth factor deprivation/ MR33583 (50 nM)
+ Growth factor deprivation/ MR33583 (10 nM)

End-point evaluation

96 hours after growth factor deprivation, the cell culture supernatant was taken off and was immediately frozen for future analysis. Cells were fixed by a cold solution of ethanol (95%) and acetic acid (5%) for 5 min at -20°C. Cells were washed twice in PBS, and then permeabilized. Non-specific sites were blocked with a solution of PBS containing 0.1% saponin and 1% FCS for 15 min at room temperature.

Immunostaining: GAD67 (survival) - The cultures were incubated for 2 h with a mouse monoclonal anti-GAD67 antibody at dilution of 1/200 in PBS containing 1% fetal calf serum and 0.1% saponin (this antibody stains specifically GABAergic neurons). This antibody was revealed with an Alexa Fluor 488 goat anti-mouse IgG (1/400 dilution) in PBS containing 1% FCS, 0.1% saponin, for 1 h at room temperature.

Automatic computer analysis - For each condition, 30 pictures (representative of the whole well area) per well was taken using ImageXpress® (Molecular Devices) with 20x magnification. All images were generated using the same acquisition parameters. From images, analyses were directly and automatically performed by Custom Module Editor® (Molecular Devices).

The following read-out was investigated: Analysis of MSNs survival (GAD67 staining, number of GABAergic neurons).

Statistical analysis

All values are expressed as mean $\pm$ SEM (standard error of the mean). Statistical analysis was performed by one-way ANOVA, followed by a Fisher's LSD test. $p < 0.05$ was considered significant.

Results

Effect of MR33583 in a primary culture of GABAergic neurons stressed by a deprivation of growth factors

Neuronal survival. A loss of large GAD-67 positive GABAergic neurons followed the deprivation of growth factors (Figure 18).

MR33583 (50 nM) exerted a significant neuroprotective effect, showed with the survival of GABAergic neurons improvement.

Discussion

Altogether, these results indicate that MR33583 was able to promote neuroprotective effects (50 nM) in GABAergic neurons and that it could be a potential drug candidate for Huntington's disease.