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Meloni

(54) **NEUROPROTECTIVE PEPTIDES**

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CPC ***A61K 38/1709*** (2013.01); ***A61K 9/0053*** (2013.01)

(57) **ABSTRACT**

The invention relates to the use of an isolated peptide of 10 to 32 amino acid residues in length for the treatment of neural injury, wherein the isolated peptide comprises at least 10 to 22 arginine residues. The peptide may be a poly-arg sequence or an arginine-rich peptide.

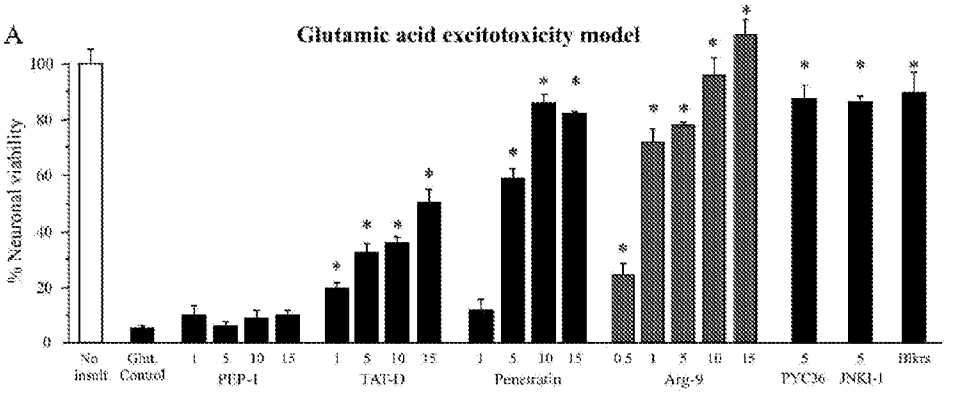


Fig.1.a

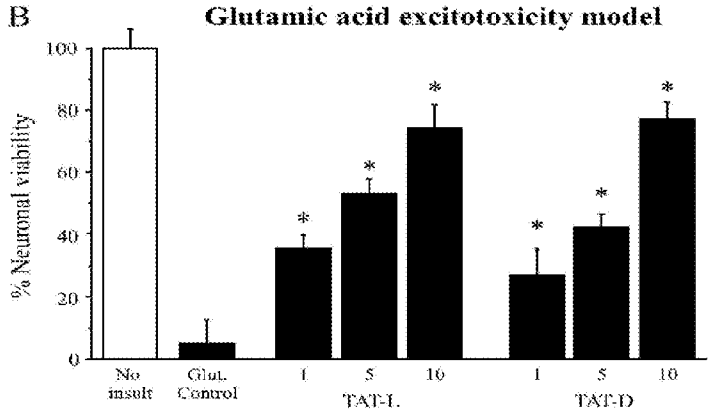


Fig. 1.b

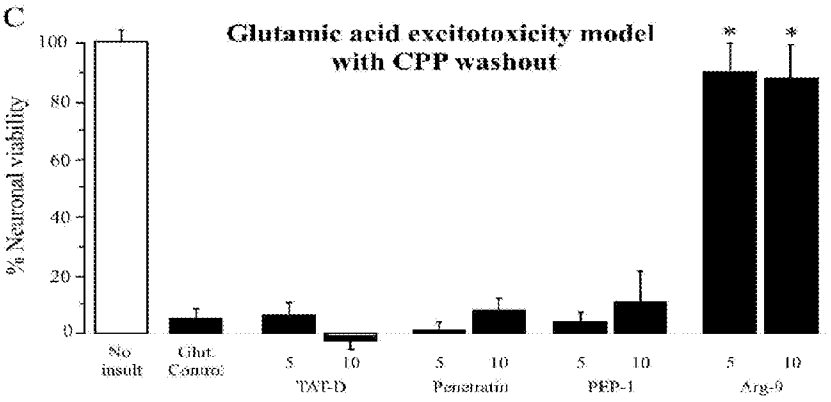


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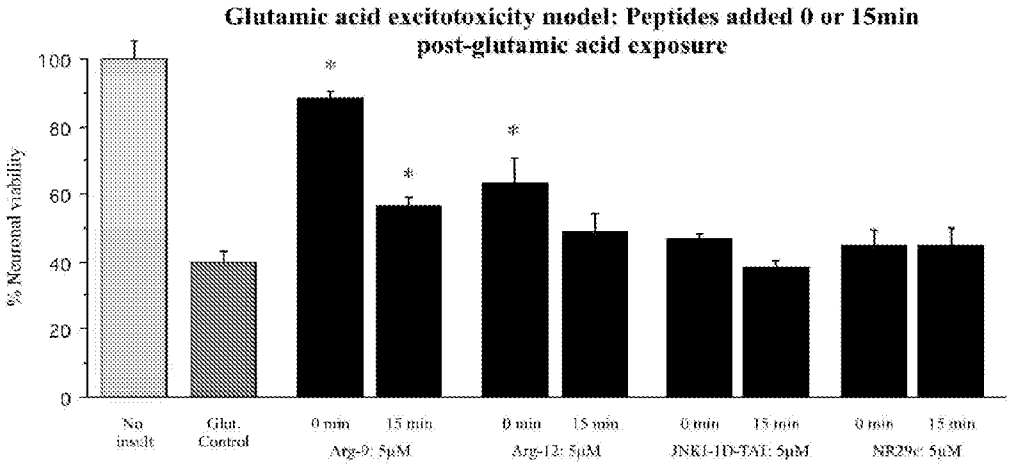


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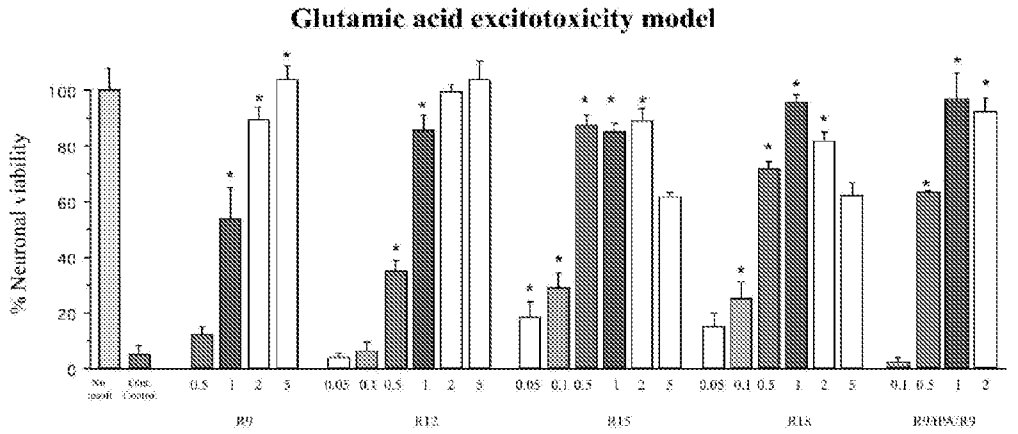


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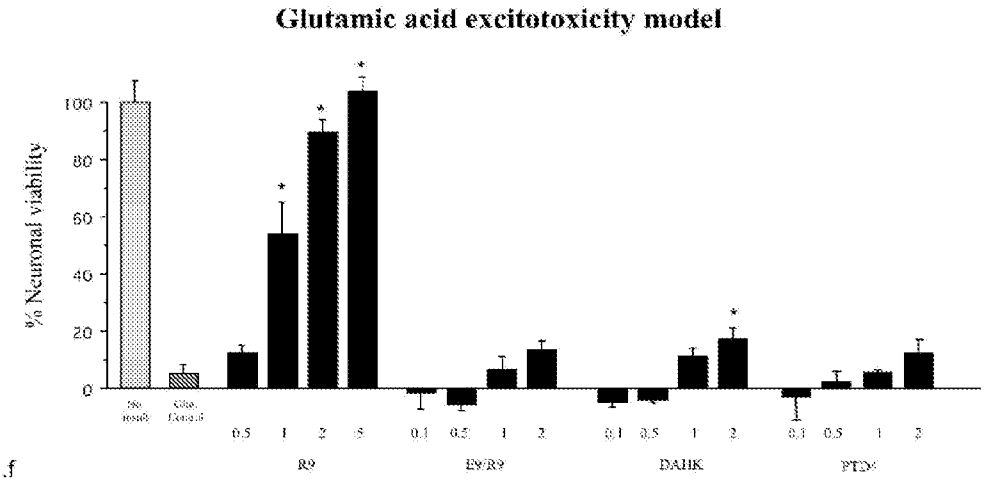


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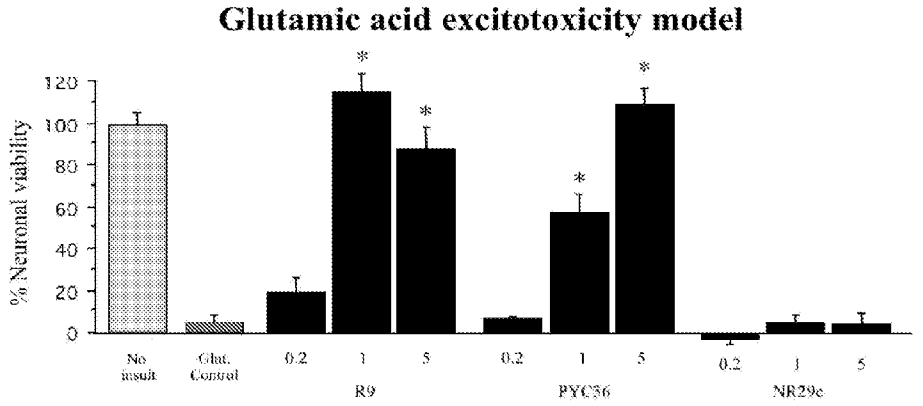


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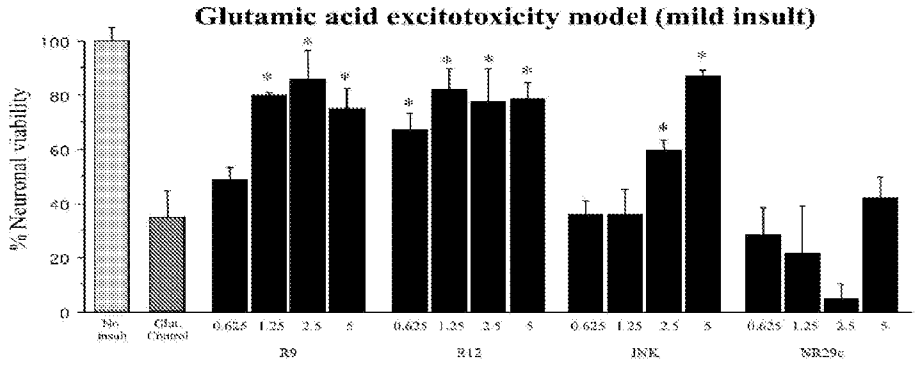


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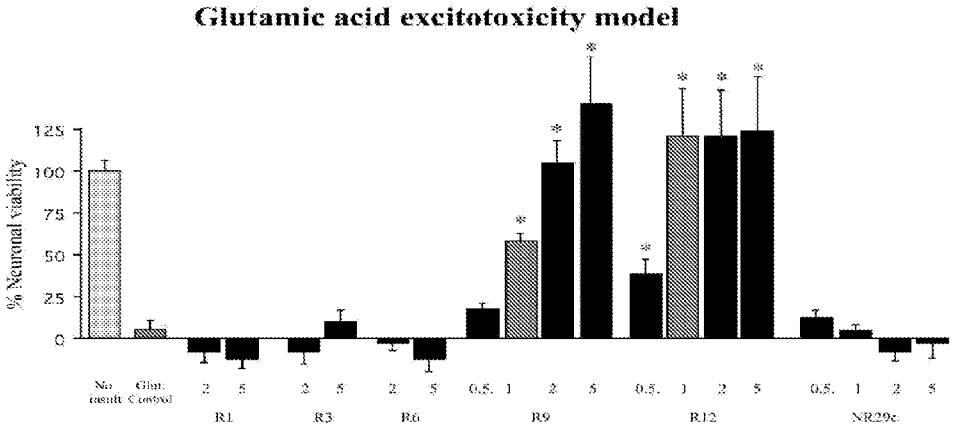


Fig. 1.i

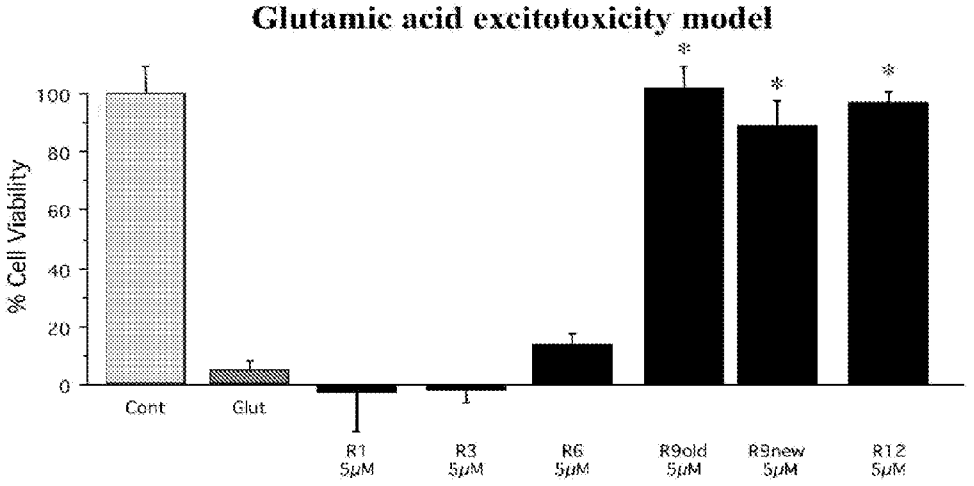


Fig. 1.j

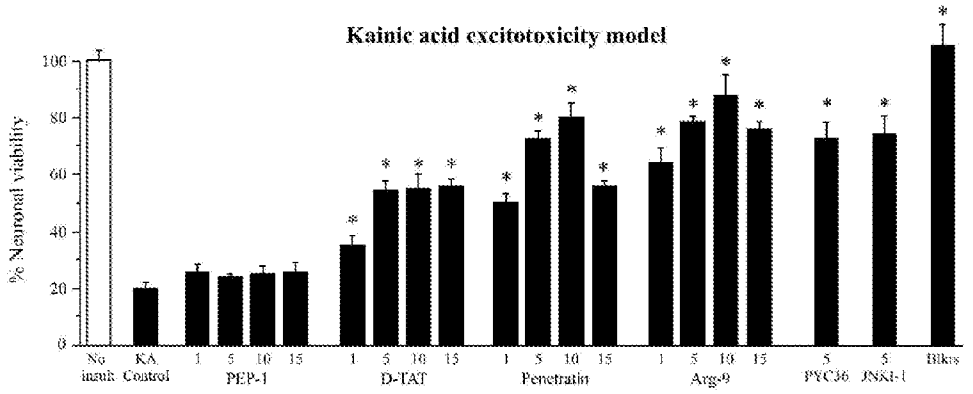


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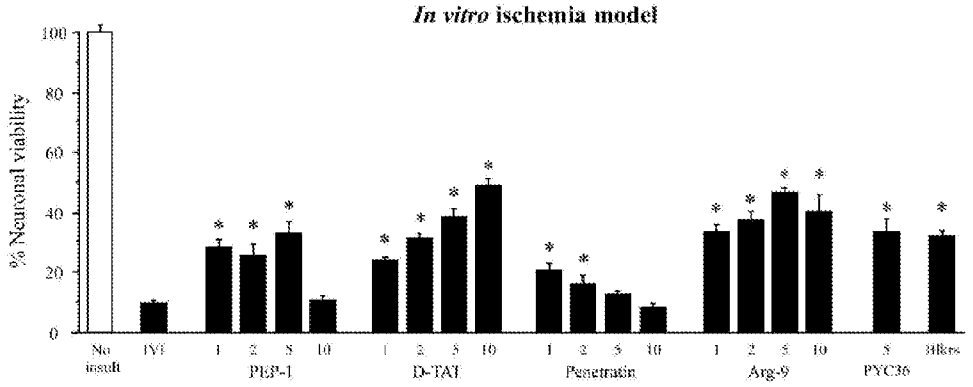


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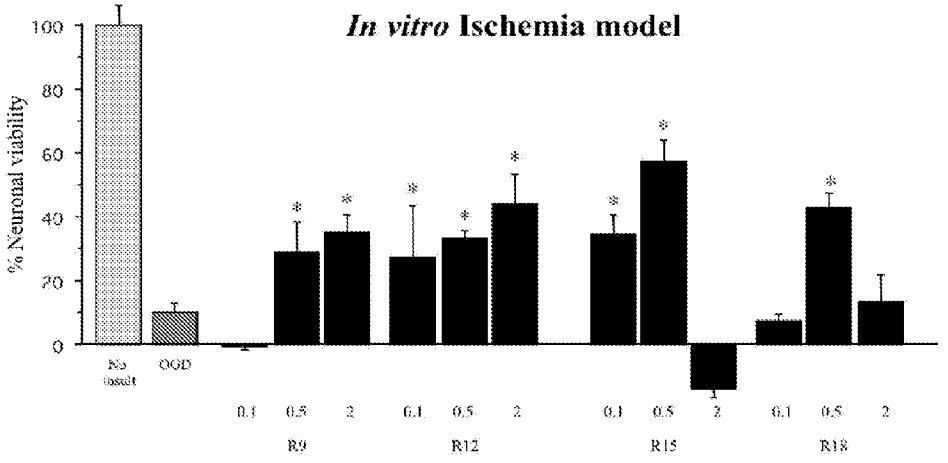


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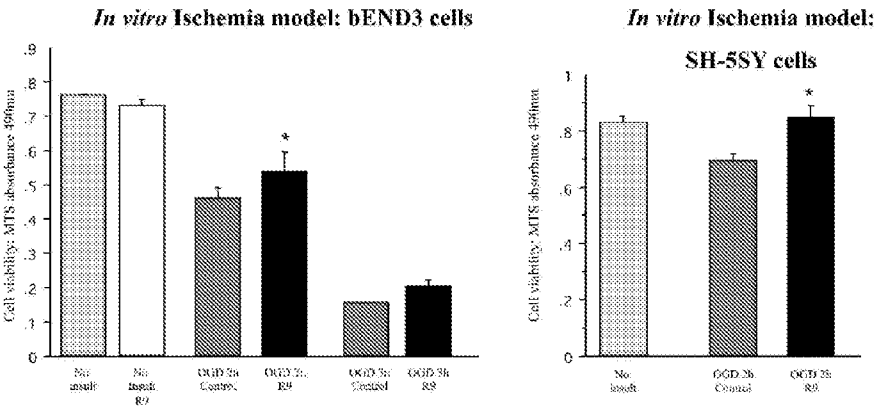


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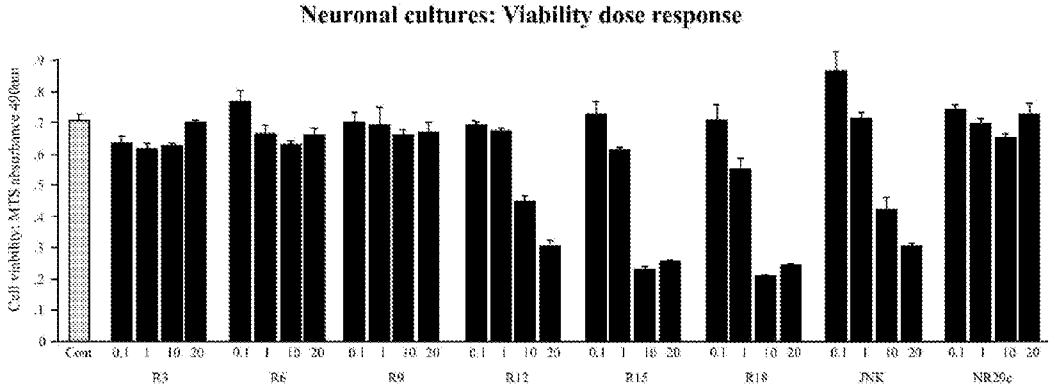


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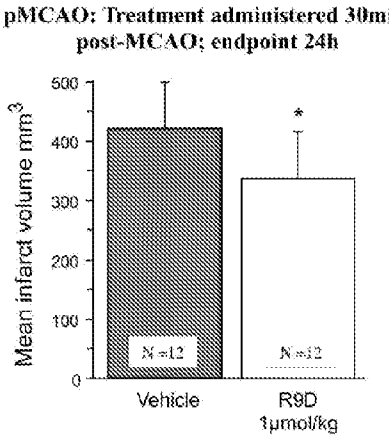


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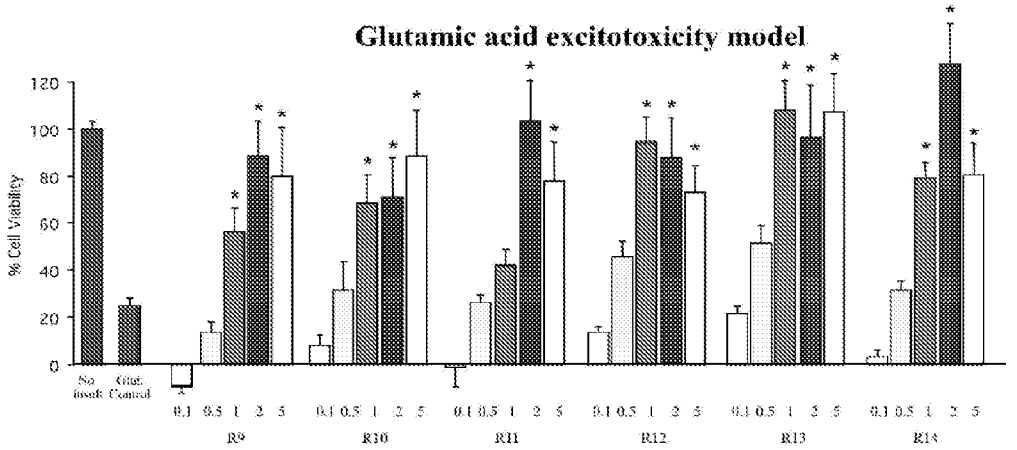


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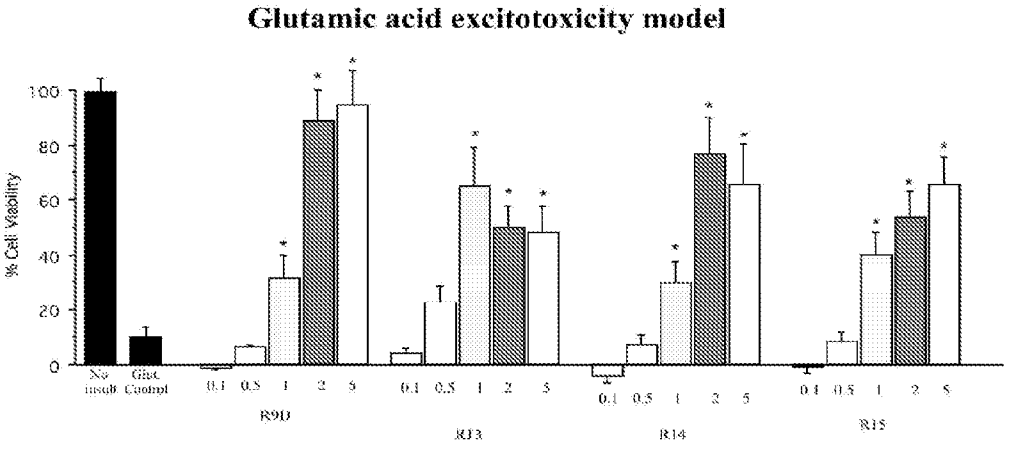


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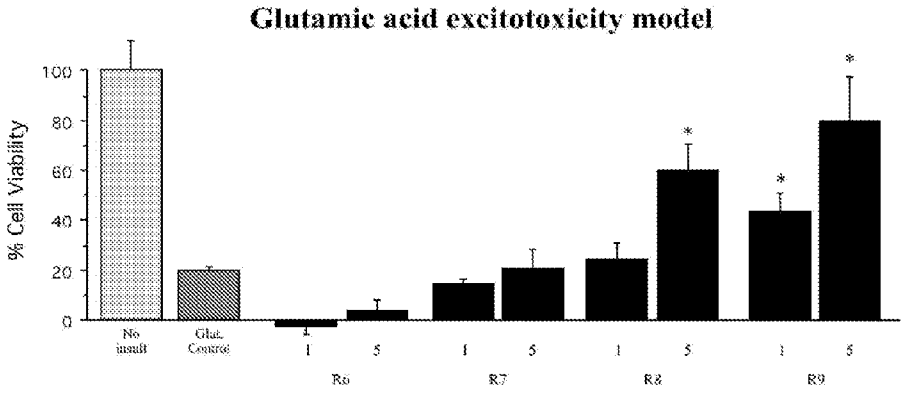


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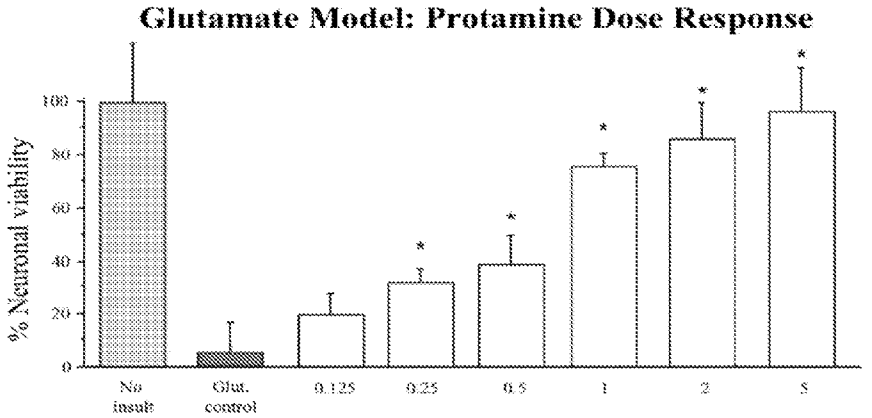


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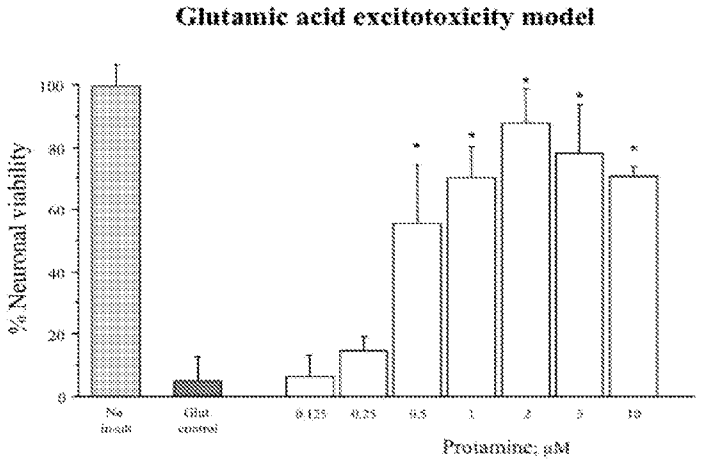


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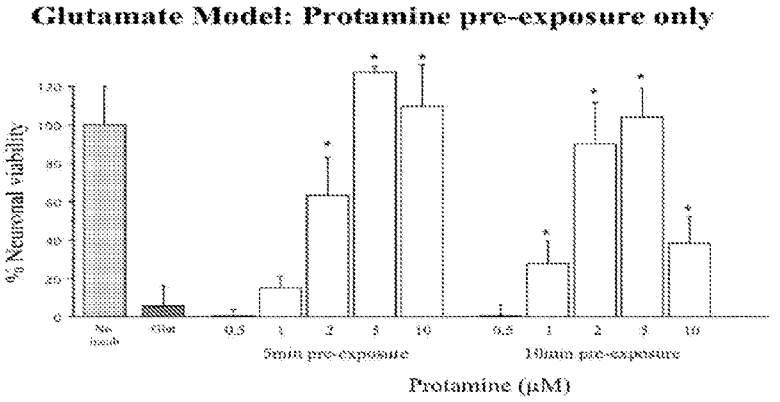


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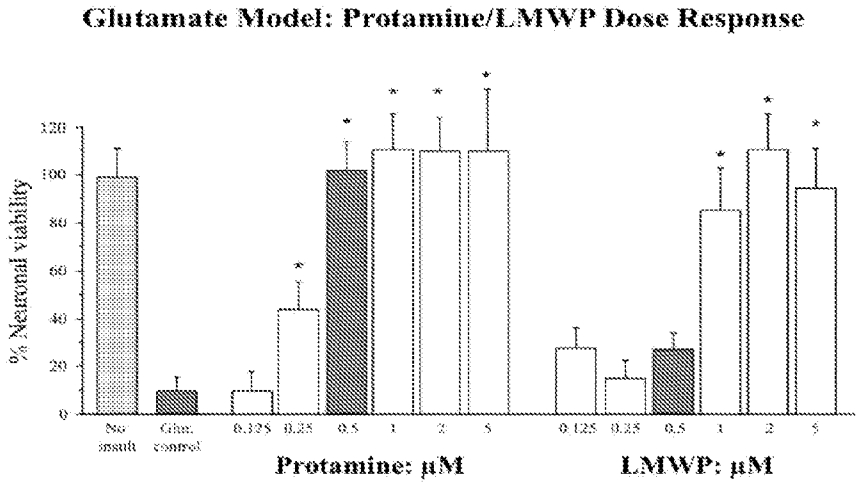


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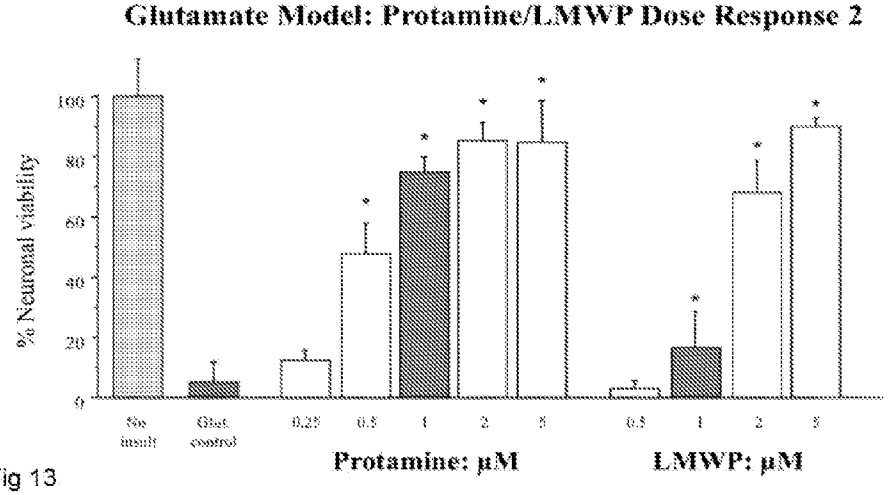


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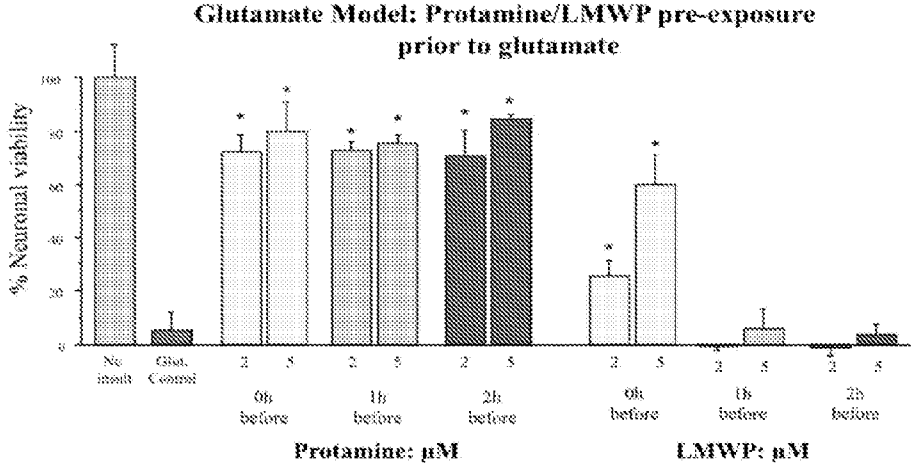


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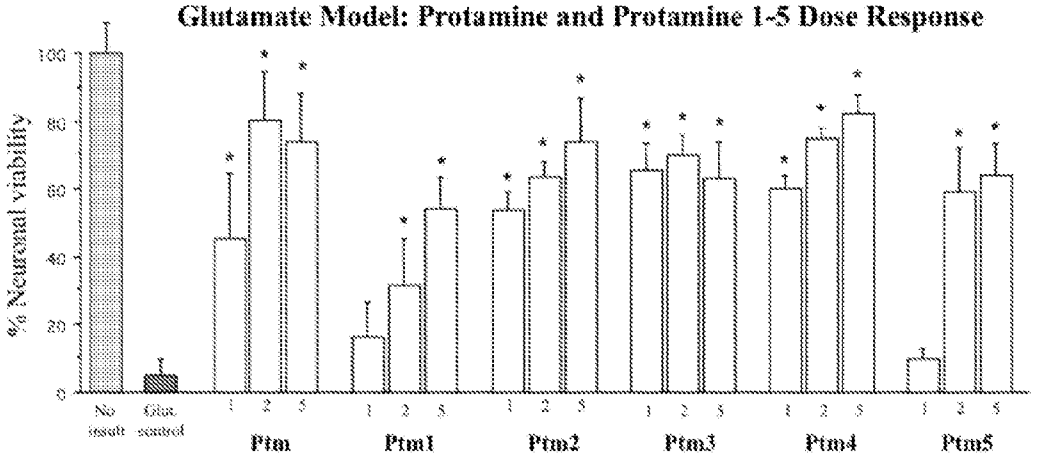


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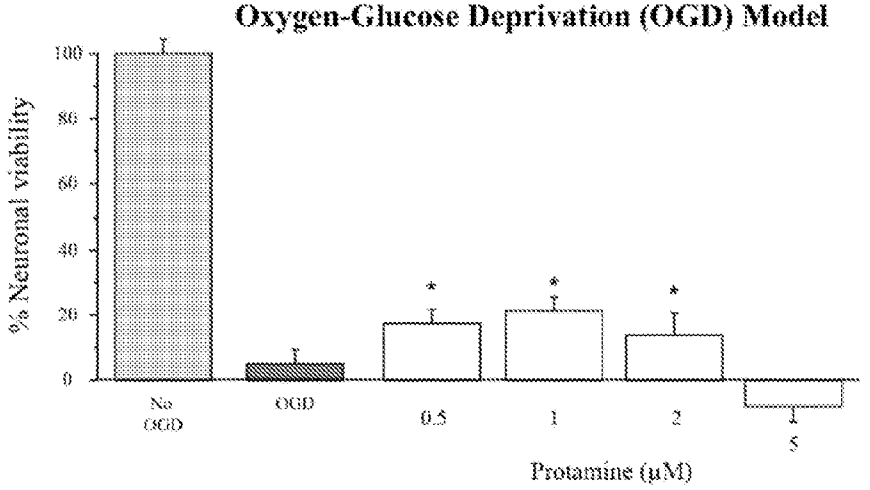


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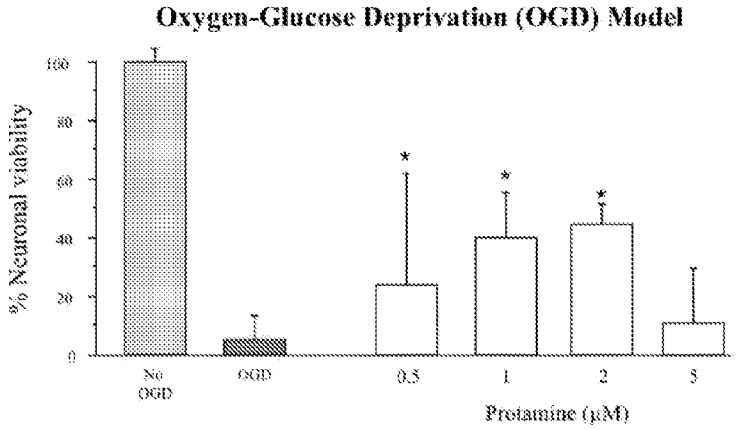


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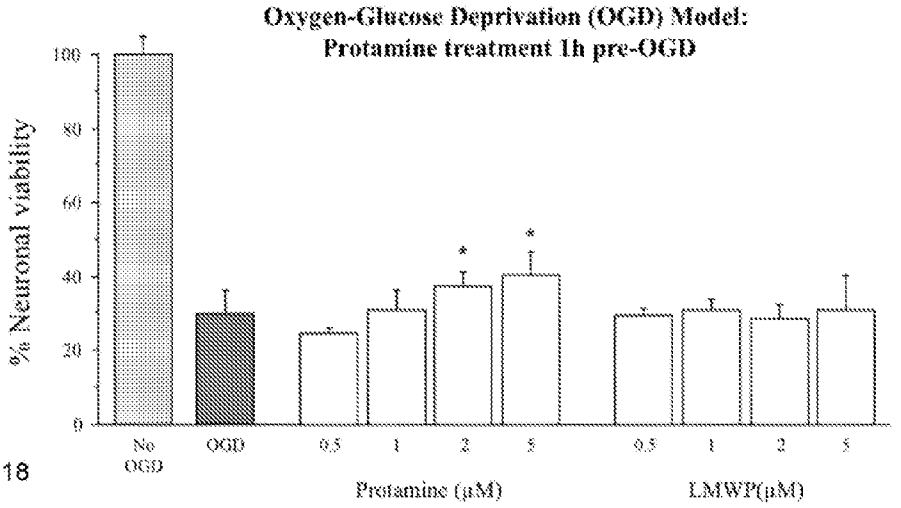


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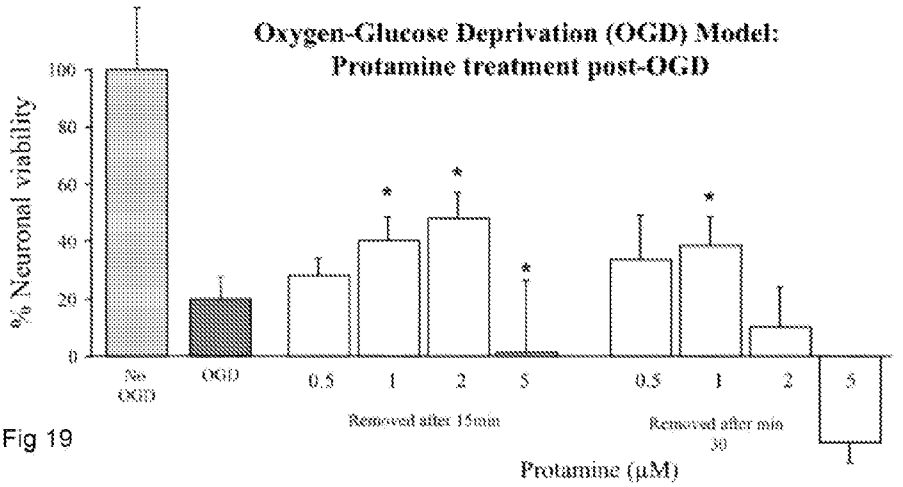


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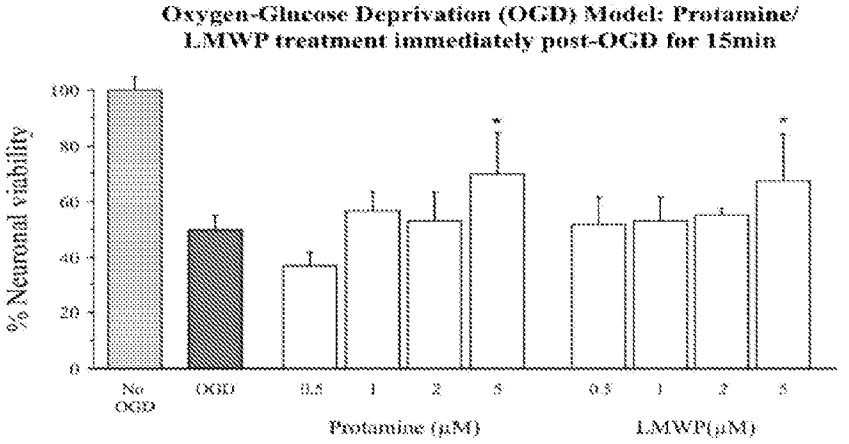


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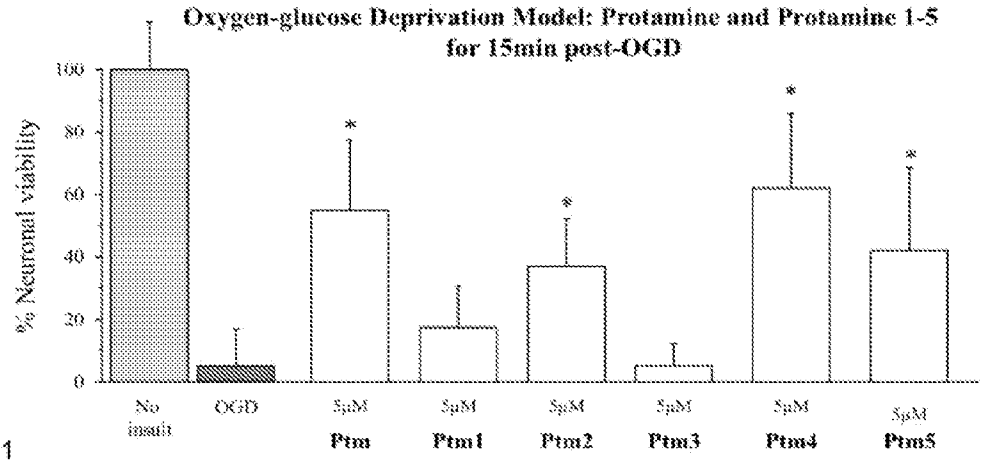


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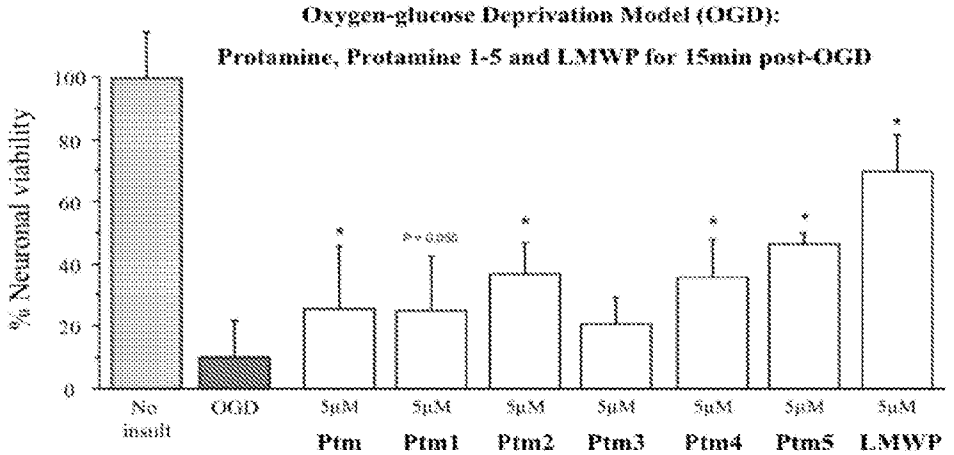


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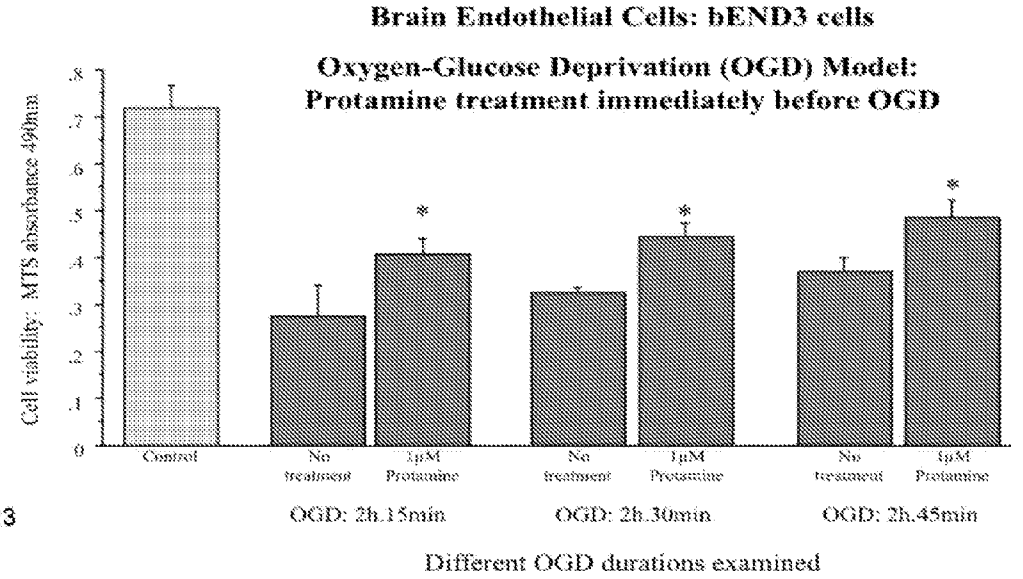

Brain Endothelial Cells: bEND3 cells
Oxygen-Glucose Deprivation (OGD) Model:
Protamine treatment immediately before OGD
Cell viability: MTS absorbance 490nm
Control
No treatment
1μM Protamine
No treatment
1μM Protamine
No treatment
1μM Protamine
OGD: 2h.15min
OGD: 2h.30min
OGD: 2h.45min
Different OGD durations examined

Fig 23

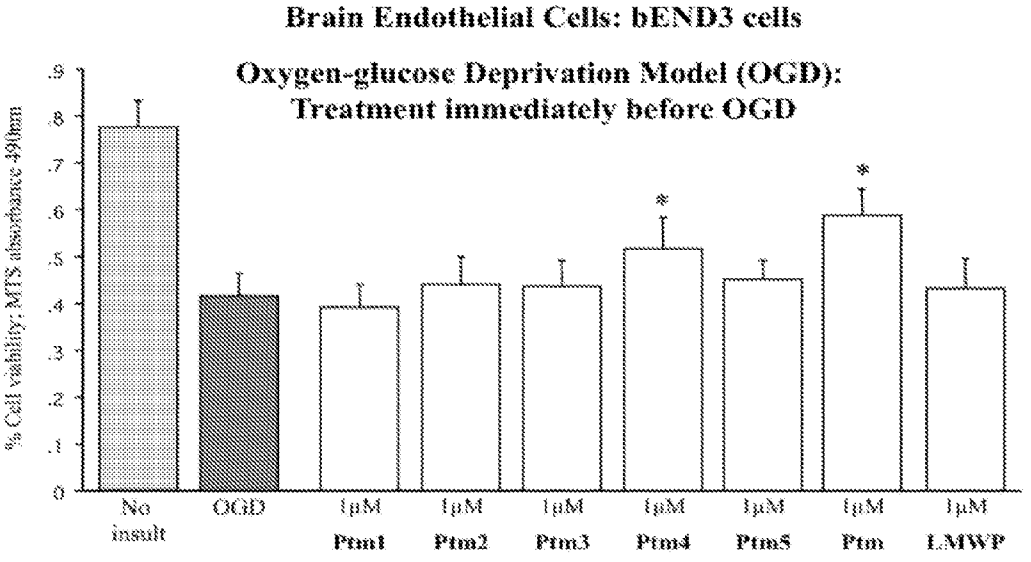

Brain Endothelial Cells: bEND3 cells
Oxygen-glucose Deprivation Model (OGD):
Treatment immediately before OGD
% Cell viability; MTS absorbance 490nm
No insult
OGD
1μM Ptm1
1μM Ptm2
1μM Ptm3
1μM Ptm4
1μM Ptm5
1μM Ptm
1μM LMWP

Fig 24

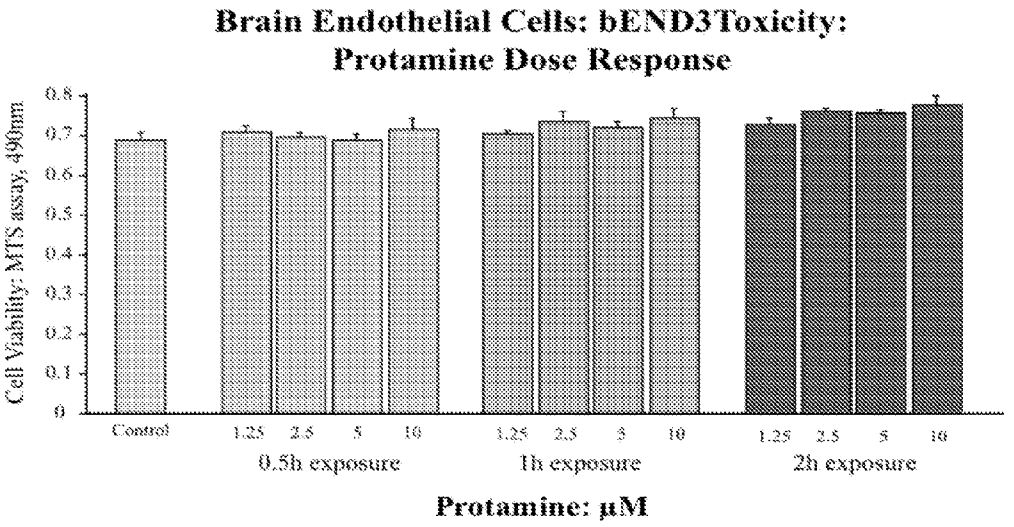

Brain Endothelial Cells: bEND3Toxicity:
Protamine Dose Response
Cell Viability: MTS assay, 490nm
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Control
1.25
2.5
5
10
0.5h exposure
1h exposure
2h exposure
Protamine: µM

Fig 25

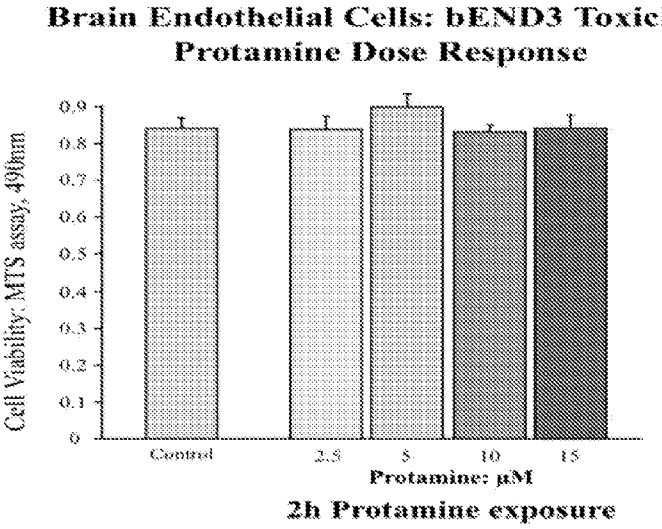

Brain Endothelial Cells: bEND3 Toxicity:
Protamine Dose Response
Cell Viability: MTS assay, 490nm
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Control
2.5
5
10
15
Protamine: µM
2h Protamine exposure

Fig 26

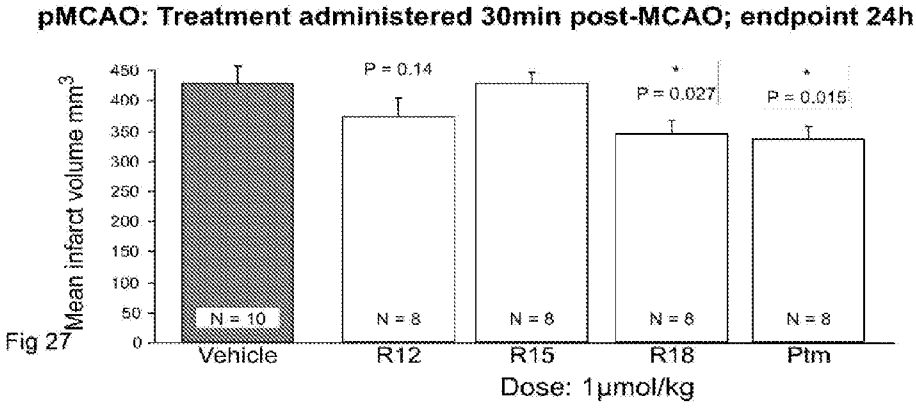


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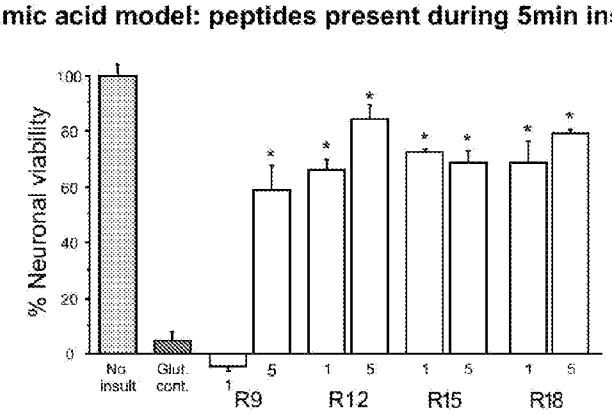


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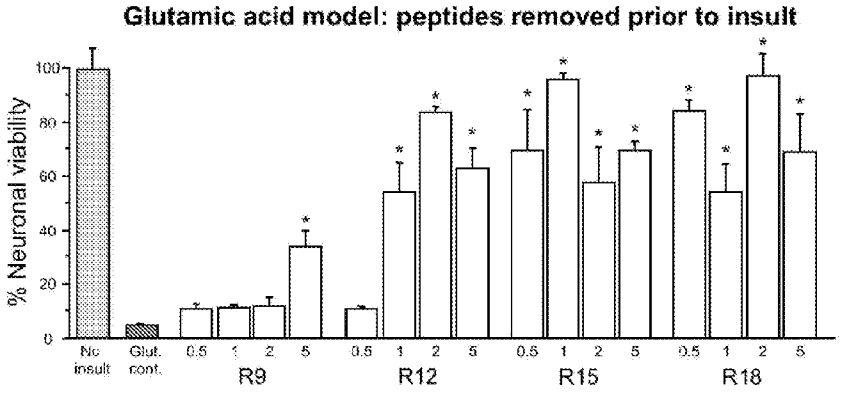


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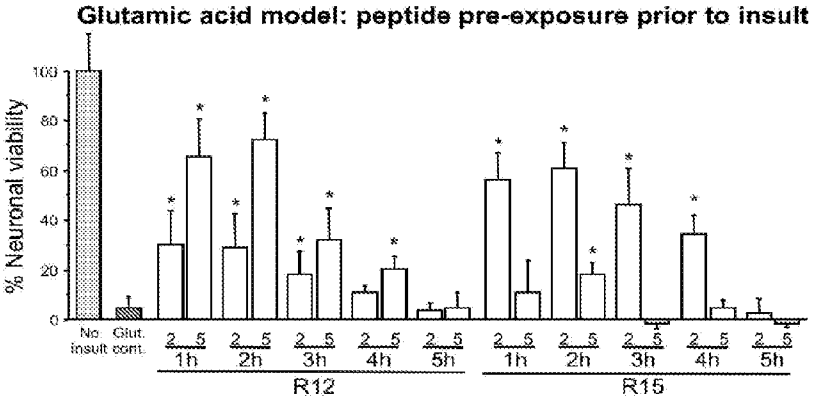


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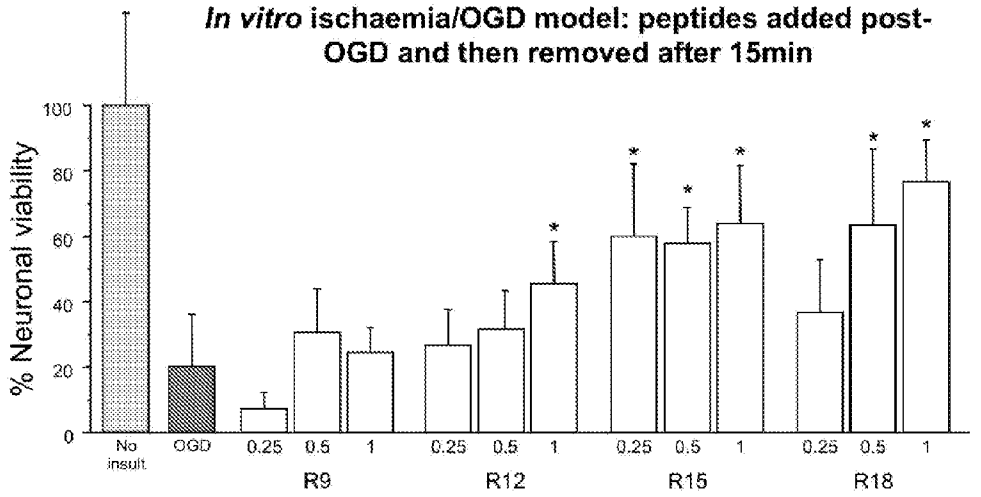


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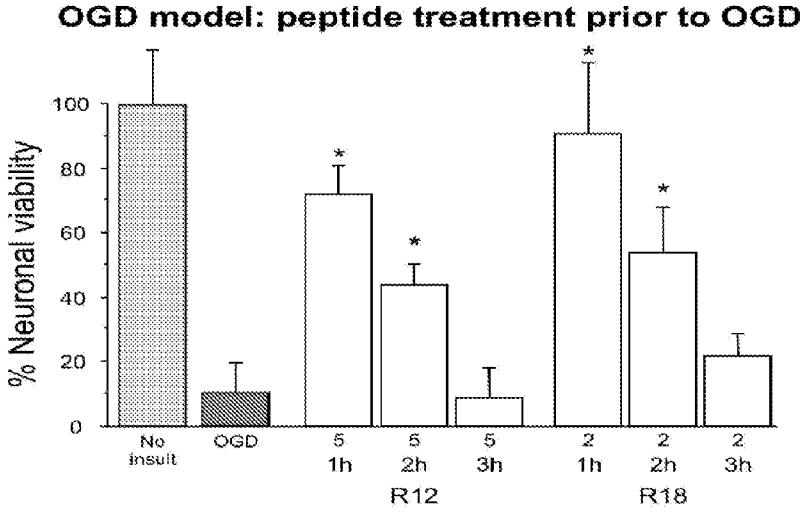


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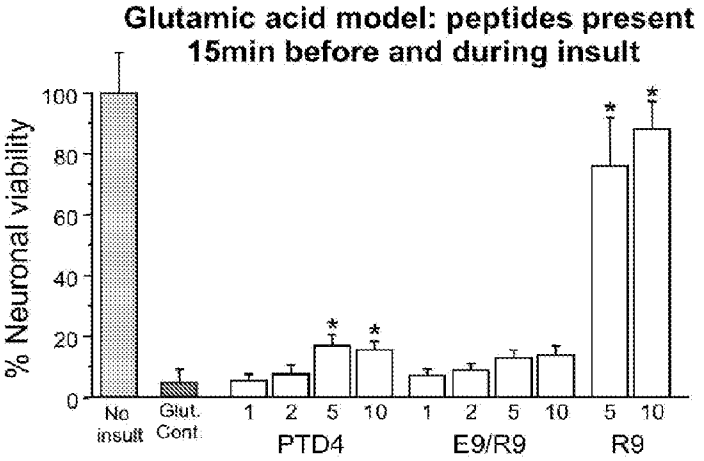


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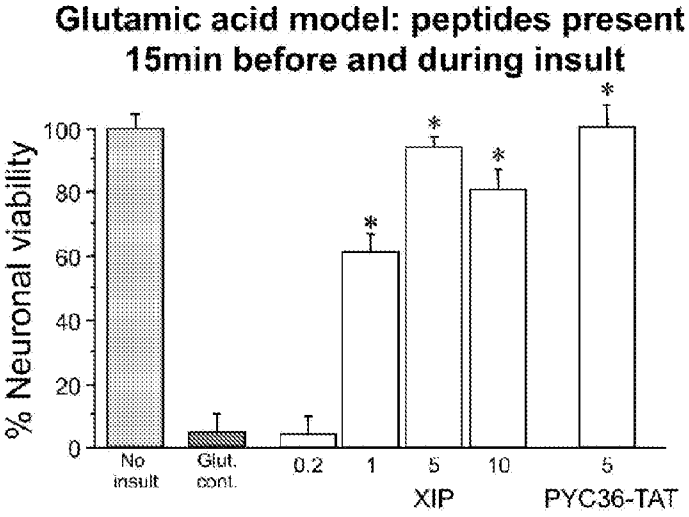


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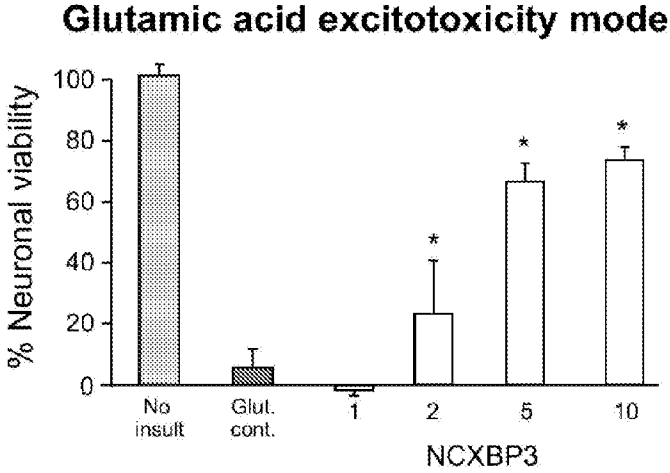


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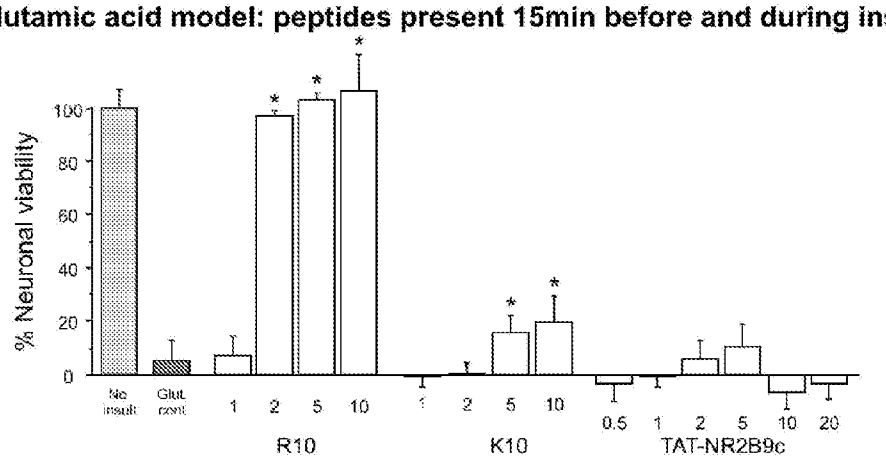


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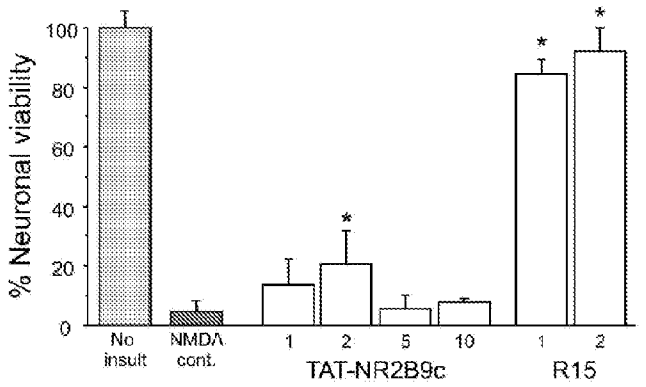


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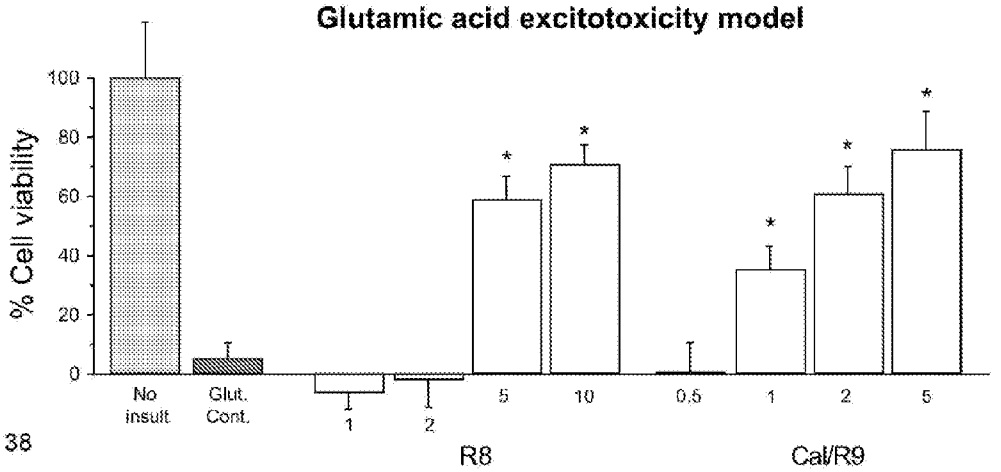


Fig 38

Glutamic acid model: peptides ± heparin; peptide removed prior to insult

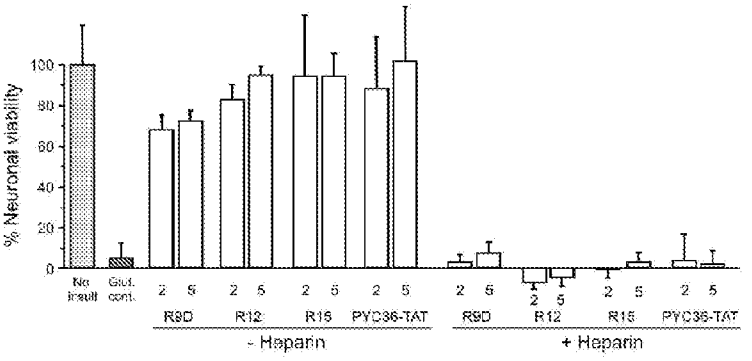


Fig 39

Glutamic acid model: peptides ± heparin; peptides removed prior to insult

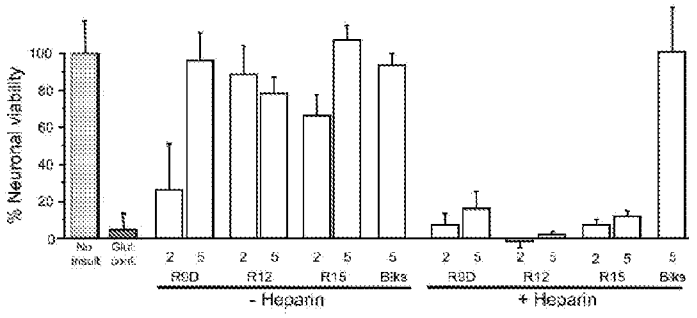


Fig 40

Glutamic acid model: peptides present 15min before and during insult

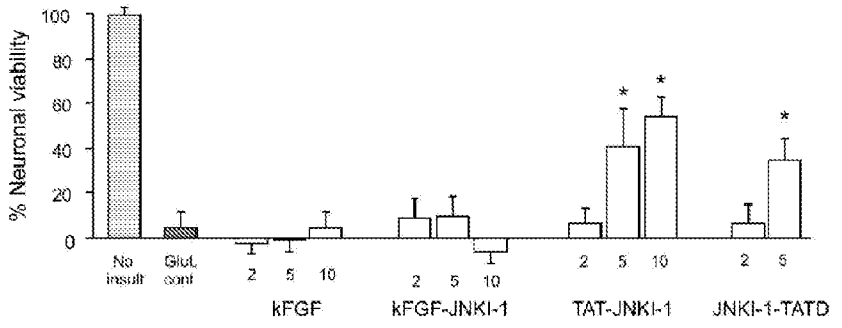


Fig 41

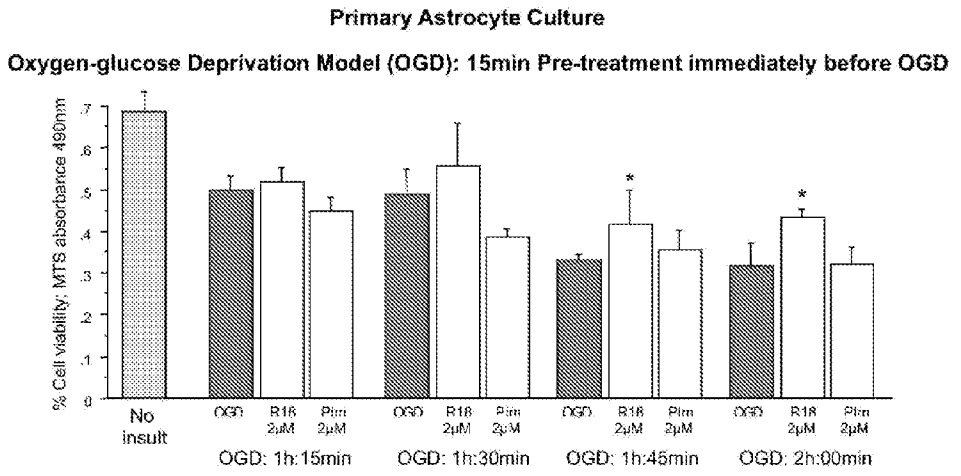

Primary Astrocyte Culture
Oxygen-glucose Deprivation Model (OGD): 15min Pre-treatment immediately before OGD
% Cell viability: MTS absorbance 490nm
No insult
OGD
R18 2μM
Ptm 2μM
OGD: 1h:15min
OGD: 1h:30min
OGD: 1h:45min
OGD: 2h:00min

Fig 42

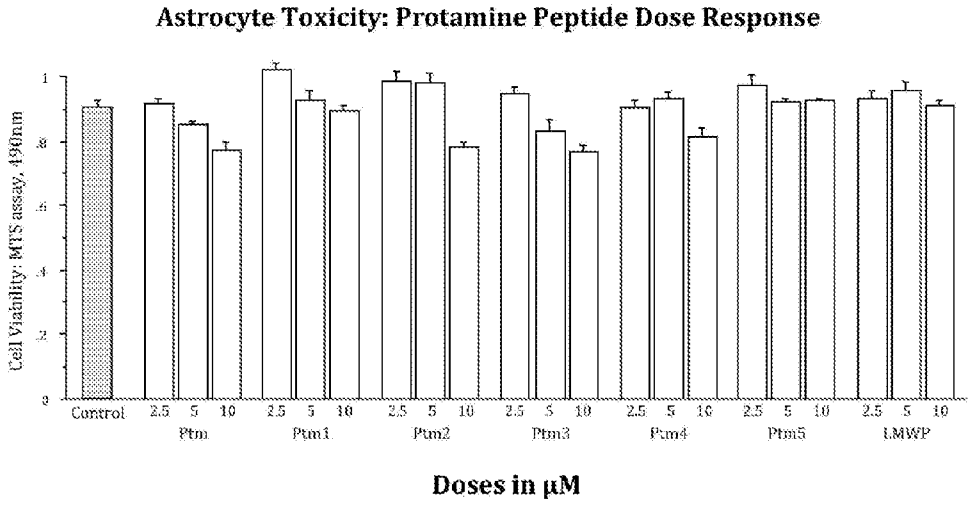

Astrocyte Toxicity: Protamine Peptide Dose Response
Cell Viability: MTS assay, 490nm
Control
2.5
5
10
Ptm
Ptm1
Ptm2
Ptm3
Ptm4
Ptm5
LMWP
Doses in μM

Fig 43

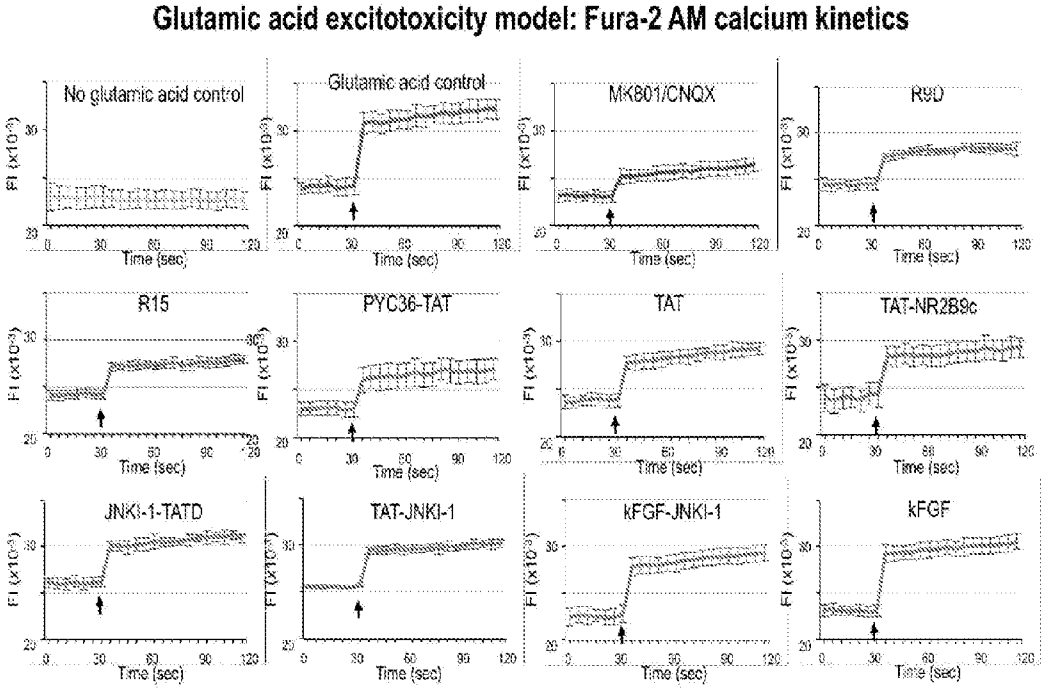

Glutamic acid excitotoxicity model: Fura-2 AM calcium kinetics
No glutamic acid control
Glutamic acid control
MK801/CNQX
R9D
R15
PYC36-TAT
TAT
TAT-NR2B9c
JNKI-1-TATD
TAT-JNKI-1
kFGF-JNKI-1
kFGF
FI (x10⁻³)
Time (sec)

Fig 44

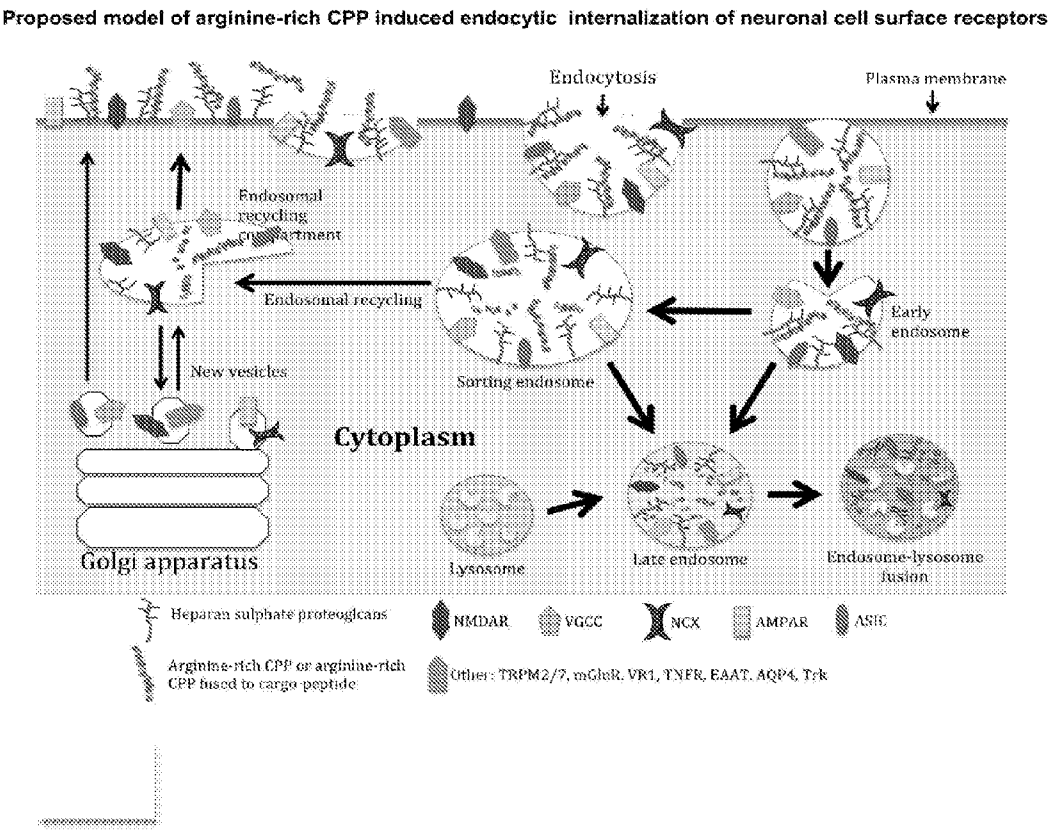

Proposed model of arginine-rich CPP induced endocytic internalization of neuronal cell surface receptors
Endocytosis
Plasma membrane
Endosomal recycling compartment
Endosomal recycling
Early endosome
New vesicles
Sorting endosome
Cytoplasm
Golgi apparatus
Lysosome
Late endosome
Endosome-lysosome fusion
Heparan sulphate proteoglcans
NMDAR
VGCC
NCX
AMPAR
ASIC
Arginine-rich CPP or arginine-rich CPP fused to cargo peptide
Other: TRPM2/7, mGluR, VR1, TNFR, EAAT, AQP4, Trk

Fig 45

Peptide	SEQ ID NO.	Sequence	No. amino acids/No. arginine residues; molecular weight (Da)	Net charge at pH 7	Physical-chemical properties
R1; Arg-1	1	H-R-OH	1/1; 174	1	Cationic
R3; Arg-3	2	H-RRR-OH	3/3; 487	3	Cationic
R6; Arg-6	3	H-RRRRRR-OH	6/6; 955	6	Cationic
R7; Arg-7	4	H-RRRRRRR-OH	7/7; 1,111	7	Cationic
R8; Arg-8	5	H-RRRRRRRR-OH	8/8; 1,267	8	Cationic
R9; Arg-9	6	H-RRRRRRRRR-OH	9/9; 1,424	9	Cationic
R10; Arg-10	7	H-RRRRRRRRRR-OH	10/10; 1,580	10	Cationic
R11; Arg-11	8	H-RRRRRRRRRRR-OH	11/11; 1,736	11	Cationic
R12; Arg-12	9	H-RRRRRRRRRRRR-OH	12/12; 1,892	12	Cationic
R13; Arg-13	10	H-RRRRRRRRRRRRR-OH	13/13; 2,048	13	Cationic
R14; Arg-14	11	H-RRRRRRRRRRRRRR-OH	14/14; 2,204	14	Cationic
R15; Arg-15	12	H-RRRRRRRRRRRRRRR-OH	15/15; 2,360	15	Cationic
R18; Arg-18	13	H-RRRRRRRRRRRRRRRRRR-OH	18/18; 2,829	18	Cationic
PTD-4[a]	14	H-YARAAARQARA-OH	11/3; 1,204	3	Cationic
E9/R9 (R9/E9)	15	H-EEEEEEEEE-RRRRRRRRR-OH	18/9; 2,586	0	Neutral
R9/tPA/R9 or R9/X7/R9	16	H-RRRRRRRRR-PGRVVGG-RRRRRRRRR-OH	25/19; 3,452	19	Cationic
DAHK	17	H-DAHK-OH	4/0; 469.5	0.1	N/A
NR2B9c-TAT[b]	18	H-GRKKRRQRRR-KLSSIESDV-NH2	19/6; 2,355		Cationic
D-R9	19	H-rrrrrrr-NH2	9/9; 1423.73	10	Cationic
TAT-D	20	H-GrrrqrrkkrG-NH2	10/6; 1,453	9	Cationic
TAT-L	21	Ac-GRKKRRQRRRG-NH2	10/6; 1,494	8	Cationic
Penetratin	22	H-RQIKIWFQNRRMKWKK-NH2	16/3; 2,246	7	Cationic
Pep-1	23	H-KETWWETWWTEWSQPK KKRKV-NH2	21/1; 2,847	4	Amphiphilic
PYC36L-TAT[c]	24	H-GRKKRRQRRR-GGLQGRRRQGYQSIKP-NH2	26/10; 3,180	13	Cationic
JNKI-1D-TAT[d]	25	H-tdqsrpvqpflnlttprkprpp-rrrqrrkkrG-NH2	32/; 3,925	12	Cationic
TAT-JNKI-1[d]	26	H-GRKKRRQRRR-PPRPKRPTTLNLFPQVPRSQDT-OH	32/9; 3,924.6	11	Cationic
kFGF-JNKI-1	27	H-AAVALLPAVLLALLAP-PPRPKRPTTLNLFPQVPRSQDT-OH	38/3; 4,043.9	3	Hydrophobic
kFGF	28	H-AAVALLPAVLLALLAP-OH	16/0; 1515.96	0	Hydrophobic
XIP[e]	29	H-RRLLFYKYVYKRYRAGKQ RG-OH	20/5; 2621.14	8	Cationic
NCXBP3[f]	30	H-RRERRRRSCAGCSRARGS CRSCRR-NH2	24/11; 2881.34	10.8	Cationic
Cal/R9	31	Ac-PLFAE-RRRRRRRRR-NH2	15/9; 2022.41	8	Cationic

Fig. 46

Summary of different protamine (salmon) peptides (and nucleic acid)

SEQ ID NO.:	Name of Sequence	Type	Other information	Sequence	aa's/arg residues	MW (da)
-	Protamine sulphate mixture; Ptm	Poly-peptide mixture	Injectable/IV form	Protamine 1 - Protamine 4[1]	32/21	≈4,500
32	Protamine 1; Ptm1	Poly-peptide	Peak 1 HPLC	PRRRRRSSSRPIRRRRR PRASRRRRRGGRRRR	32/21	4,236
33	Protamine 2; Ptm2	Poly-peptide	Peak 2 HPLC	PRRRRSSRRPVRRRRR PRVSRRRRRGGRRRR	31/21	4,163
34	Protamine 3; Ptm3	Poly-peptide	Peak 3 HPLC	PRRRRSSSRPVRRRRR PRVSRRRRRGGRRRR	31/20	4,094
35	Protamine 4; Ptm4	Poly-peptide	Peak 4 HPLC	PRRRRASRRIRRRRRPR VSRRRRRGGRRRR	30/21	4,064
36	Protamine 5; Ptm5	Poly-peptide	SwissProt	PRRRRSSSRPVRRRRR PRVSRRRRRRGGRRRR	32/21	4,250
37	Low molecular weight protamine (LMWP)	Poly-peptide	Derived from protamine	VSRRRRRRGGRRRR	14/10	1,880
38	Protamine 5 nucleotide sequence	Ptm 5, DNA coding sequence	SwissProt	5'ATGCCCAGAAGACGC AGATCCTCCAGCCGAC CTGTCCGCAGGCGCCG CCGCCCTAGGGTGTCC CGACGTCGTCGCAGGA GAGGAGGCCGCAGGA GGCGT-3'	N/A	N/A

Fig. 47

NEUROPROTECTIVE PEPTIDES

FIELD OF THE INVENTION

[0001] This invention relates to peptides having neuroprotective activity, the peptides being useful in treating stroke and other neural injuries or disorders. The invention relates further to a method of treating a neural injury or disorder using the peptides of the invention.

BACKGROUND OF THE INVENTION

[0002] Cell penetrating peptides (CPPs) are small peptides that are used to facilitate the delivery of normally non-permeable cargos such as other peptides, proteins, nucleic acids or drugs into cells.

[0003] The development of cell penetrating peptides (CPPs), also referred to as peptide transduction domains (PTDs), as facilitators of therapeutic drug delivery has progressed significantly since the initial discovery of a PTD within the human immunodeficiency virus-type 1 trans-activating transcriptional activator (Frankel and Pabo, 1988; Green and Loewenstein, 1988), commonly referred to as TAT. Since then, the active transporting portion of this sequence has been isolated (TAT_{48-58}: referred to as the TAT peptide), as well as the discovery and synthesis of over 100 novel CPPs (Milletti, 2012).

[0004] Potential therapeutics fused to CPPs have been assessed in neuronal culture systems and animal models that mimic neural injury mechanisms in a variety of disorders, including cerebral ischemia, epilepsy, Parkinson's disease and Alzheimer's diseases (Lai et al. 2005; Liu et al. 2006; Arthur et al. 2007; Colombo et al. 2007; Nagel et al. 2008; Meade et al, 2009). The use of CPPs for neurological disorders is especially attractive due to their ability to transport cargo across the blood brain barrier and then enter into neural cells within the brain parenchyma (Aarts et al. 2002; Zhang et al. 2013). Two examples of CPP-fused neuroprotective peptides that have entered clinical trials are the JNK inhibitor peptide (JNKI-1D-TAT or XG-102; ARAMIS, 2012) and the NMDA receptoripostsynaptic density-95 inhibitory peptide (TAT-NR2B9c or NA-1; Dolgin 2012). Both peptides are fused to TAT.

[0005] An important feature of any CPP is limited toxicity at clinically relevant doses, and there is a great need for CPPs of limited toxicity. Similarly, there is a great need when treating neural injuries for peptides that are neuroprotective. The structures and amino acid content of CPPs vary wildly and it has recently been shown that the TAT peptide, the most widely used CPP used in neuroprotection experiments, appears to also possess intrinsic neuroprotective properties. Recent studies (Xu et al, 2008; Vaslin et al. 2009; Meade et al. 2010a,b; Craig et al. 2011) have reported that the TAT peptide displays neuroprotective actions in vitro following excitotoxicity and oxygen-glucose deprivation, and in vivo following cerebral ischemia in P12 rats after intraventricular injection. While the exact mechanisms of TAT's neuroprotective action are not fully understood, there is speculation that it interferes with NMDA receptor activation (Xu et al. 2008; Vaslin et al. 2009), although one study failed to detect a binding interaction (Li et al. 2008). Additionally, in an RNAi study using CPPs to deliver constructs, both the TAT and penetratin peptides alone were shown to down-regulate MAP kinase mRNA in the lung following intratracheal administration (Moschos et al. 2007).

[0006] Neuronal or neural injuries or disorders such as migraine, stroke, traumatic brain injury, spinal cord injury, epilepsy and neurodegenerative disorders including Huntington's Disease (HD), Parkinson's Disease (PD), Alzheimer's Disease (AD) and Amyotrophic Lateral Sclerosis (ALS) are major causes of morbidity and disability arising from long term brain or spinal cord injury. The brain injuries generally involve a range of cell death processes including apoptosis, autophagy, necroptosis and necrosis, and affect neurons astrocytes, oligodentrocytes, microglia and vascular endothelial cells (collectively referred to as the neurovascular unit; NVU). The damaging triggers involved in neural injury involve diverse pathways involving glutamate excitotoxicity calcium overload, oxidative stress, proteolytic enzymes and mitochondrial disturbances.

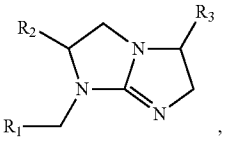
[0007] As used herein, the term "stroke" includes any ischemic disorder affecting the brain or spinal cord, e.g. thrombo-embolic occlusion in a brain or spinal cord artery, severe hypotension, perinatal hypoxia-ischaemia, a myocardial infarction, hypoxia, cerebral haemorrhage, vasospasm, a peripheral vascular disorder, a venous thrombosis, a pulmonary embolus, a transient ischemic attack, lung ischemia, unstable angina, a reversible ischemic neurological deficit, adjunct thrombolytic activity, excessive clotting conditions, cerebral reperfusion injury, sickle cell anemia, a stroke disorder or an iatrogenically induced ischemic period such as angioplasty, or cerebral ischemia.

[0008] Increased extracellular levels of the neurotransmitter glutamate can cause neuronal cell death via acute and delayed damaging processed caused by excitotoxicity. An accumulation of extracellular glutamate over-stimulates NMDA and AMPA receptors resulting in an influx of extracellular calcium and sodium ions and the release of bound calcium from intracellular stores. Over-activation of NMDA receptors can also trigger the production of damaging molecules (eg. nitric oxide, CLCA1; calcium-activated chloride channel regulator 1, calpain, SREBP1: sterol regulatory element binding protein-1) and signaling pathways (e.g. DAPK; death-associated protein kinase, CamKII: calcium-calmodulin-dependent protein kinase II). In addition, glutamate-induced neuronal depolarization and excitotoxicity can trigger further intracellular calcium influx via voltage-gated calcium channels (VGCC, e.g. CaV2.2, CaV3.3), the sodium calcium exchanger (NCX), acid-sensing ion channels (ASIC), transient receptor potential cation channels 2 and 7 (TRPM2/7) and metabotropic glutamate receptors (mGluR).

[0009] The increase in intracellular calcium initiates a range of cell damaging events involving phospholipases, proteases, phosphatases, kinases, NADPH oxidase and nitric oxide synthase, as well as the activation of pathways triggering cell death (i.e. apoptosis, autophagy, necroptosis and necrosis).

[0010] Examples of compounds used to treat the neurodegenerative effects of cerebral ischemia include U.S. Pat. No. 5,559,095, which describes a method of treating ischemia related neuronal damage using omega-conotoxin peptides and related peptides which bind to and block voltage-gated calcium channels, and U.S. Pat. No. 4,684,624, which describes treatment using certain opioid peptides. Further examples include US 2009/0281036 that discloses the use of fusion peptides linked to other peptides for reducing damaging effects of injuries to mammalian cells by inhibiting the interaction of NMDA receptor and NMDAR interacting proteins. Similarly, US2012/0027781 discloses the use of linked

targeting peptides and other peptides to provide neuroprotective functioning. U.S. Pat. No. 6,251,854 discloses compounds that provide protection against excitotoxic neuronal damage which are selected from short arginine-rich oligopeptides combined with compounds of formula 1:



[0011] Many potential neuroprotective agents also exhibit toxicity at low to moderate doses. Many CPPs also exhibit toxicity at low to moderate doses. There is a need thus for neuroprotective peptides which are effective at low doses, which exhibit low cellular toxicity, and which provide protection against more than one type of neural injury.

[0012] This discussion of the background art is intended to facilitate an understanding of the present invention only. No acknowledgement or admission that any of the material referred to is, or was, part of the common general knowledge as at the priority date of the application is intended.

SUMMARY OF THE INVENTION

[0013] According to one aspect of the invention, there is provided the use of an isolated, basic (i.e cationic) amino acid-rich peptide as a neuroprotective agent. The isolated peptide may be a CPP.

[0014] As such, the invention extends to an isolated, cationic amino acid-rich peptide having neuroprotective activity. The invention extends to functional fragments of the peptide that exhibit neuroprotective activity.

[0015] The peptide may have a net charge of 8 or higher at pH 7, preferably 10 or higher at pH 7, most preferably 11 or higher at pH 7.

[0016] The peptide may be a non-naturally occurring peptide. As such, the peptide of the invention may be a man-made peptide.

[0017] The cationic (i.e. basic) amino acid residues forming part of the peptide may be arginine or lysine. Thus, the peptide may be arginine-rich. Alternatively, or additionally, the peptide may be lysine-rich, and/or tryptophan-rich.

[0018] The peptide may be between 10 amino acids and 100 amino acids in length, preferably between 10 amino acids and 32 amino acids.

[0019] The peptide may have the sequence:

$$X_{(K)}\text{-}Z_{(N)}\text{-}X_{(K)}\text{-}Z_{(N)}\text{-}X_{(K)}$$

[0020] wherein X may be any naturally occurring or synthetic amino acid, including a cationic (i.e. basic) amino acid residue;

[0021] K is an integer between 1 and 5;

[0022] Z is a basic (i.e. cationic) amino acid residue; and

[0023] N is an integer between 1 and 30.

[0024] Substitution at "X" positions with amino acids which do not decrease the neuroprotective effects of the neuroprotective peptides are preferred. In one embodiment, Z may be arginine. In another embodiment, Z may be lysine. The peptide may include at least one contiguous arginine-rich segment. In other embodiments, the peptide may include a non contiguous arginine-rich segment.

[0025] The basic (i.e. cationic) amino acid residues may be included at a ratio of at least 30% of the peptide or segment, preferably at least 40%, preferably at least 50%, more preferably at least 60%, in some cases as high as 100% of the peptide or segment. The peptide may have an arginine content of more than 20% of the amino acid content of the peptide, preferably more than 30%, more than 40%, more than 50%, more than 60%, more than 70% more than 80%, more than 90, more than 95%, more than 99%, or most preferably 100%. In certain embodiments of the invention, the peptide may have a combined arginine and lysine content of more than 40%, more than 50%, more than 60%, more than 70% more than 80%, more than 90, more than 95%, more than 99%, or most preferably 100%.

[0026] The peptide may include a plurality of single cationic amino acid residues, such as arginine residues, interspersed by other amino acid residues, in particular, it may be interspersed with basic (i.e. cationic) amino acid residues, such as lysine, and/or tryptophan. The peptide may include repeats of arginine residues in adjacent positions, such as RR, or RRR, or RRRR, or higher order repeats, and may be interspersed between other amino acids, or between stretches of amino acids.

[0027] As such, the peptide may be comprised completely of cationic amino acids. In one embodiment, the peptide is comprised completely of arginine residues.

[0028] According to an aspect of the invention, there is provided use of an isolated peptide of 10 to 32 amino acid residues in length for the treatment of neural injury, wherein the isolated peptide comprises at least 10 to 22 residues.

[0029] In a preferred embodiment of the invention, the peptide may be an isolated peptide of 10 to 32 amino acid residues in length for the treatment of neural injury, wherein the isolated peptide comprises at least 10 to 22 arginine residues.

[0030] The isolated peptide may have an arginine residue content of at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, or at least 99%.

[0031] The isolated peptide may be a poly-arginine peptide comprising 10 to 18 arginine residues. In a preferred embodiment, the isolated peptide is R12, R15, or R18, most preferably R15.

[0032] Specifically, the isolated peptide may comprise any one or more of the peptides selected from the group consisting of SEQ. ID. NOS. SEQ. ID. NOS. 7, 8, 9, 10, 11, 12, 13, 16, 30, 31, 32, 33, 34, 35, 36, 37, and functional fragments and analogues thereof having neuroprotective activity.

[0033] The isolated peptide may include at least one poly-arginine segment comprising at least 4 contiguous arginine residues, preferably at least two poly-arginine segments, more preferably three poly-arginine segments.

[0034] The isolated peptide may be penetratin (SEQ. ID. NO. 22).

[0035] The isolated peptide may comprise a mix of protamine derivatives. The mix of protamine derivatives may comprise protamine sulphate.

[0036] The isolated peptide may affect the endocytotic processes of the cell; affect the function of cell surface receptors to result in reduced cellular calcium influx; interact with and/or stabilises the outer mitochondrial membrane to preserve mitochondrial function; or inhibit, downregulate, or affect the calcium-dependent pro-protein convertase enzyme furin.

[0037] The isolated peptide may be a synthetic peptide or a man-made peptide. The isolated peptide may be included within, or fused to, other polypeptides. The isolated peptides may be fused to one another with at least one linker sequence

[0038] The isolated peptide may exhibit neuroprotective activity at IC_{50} levels of less than 50 μM, preferably less than 20 μM, most preferably less than 10 μM.

[0039] The invention extends to the use of an isolated peptide comprising any one or more of SEQ. ID. NOS. SEQ. ID. NOS. 7, 8, 9, 10, 11, 12, 13, 16, 30, 31, 32, 33, 34, 35, 36, 37, and functional fragments or analogues thereof having neuroprotective activity, in the manufacture of a pharmaceutical composition or medicament for treating or preventing neural injury.

[0040] The pharmaceutical composition or medicament may be used for the treatment or prevention of a neural injury, the pharmaceutical composition or medicament including the isolated peptide of the invention or the polynucleotide sequence of the invention.

[0041] The pharmaceutical composition or medicament may be used in the treatment or prevention of ischemia, perinatal hypoxi-ischemia, Alzheimer's disease, Huntington's Disease, Multiple Sclerosis, Parkinson's disease, amyotrophic lateral sclerosis, stroke, peripheral neuropathy, spinal cord injury, or epilepsy.

[0042] The pharmaceutical composition or medicament may comprise a pharmaceutically acceptable carrier, adjuvant, or vehicle.

[0043] According to another aspect of the invention there is provided a method of treating a neural injury or promoting survival of neurons, the method including the steps of administering to a patient in need thereof a pharmaceutically acceptable and/or pharmaceutically effective amount of the peptide of the invention or the pharmaceutical composition or medicament of the invention.

[0044] According to a still further aspect of the invention there is provided a method for inhibiting neuronal cell death in a subject comprising administering to a subject in need of such treatment a pharmaceutically acceptable and/or pharmaceutically effective amount of the peptide of the invention or the pharmaceutical composition or medicament of the invention.

[0045] Administration may be from 0.001 mg/kg to 50 mg/kg.

[0046] The invention extends to kit comprising the pharmaceutical composition or medicament of the invention in one or more container(s) and an instruction manual or information brochure regarding instructions and/or information with respect to application of the pharmaceutical composition.

[0047] More specifically, the peptide may be any one or more of the peptides having the sequences set forth as SEQ. ID. NOS. SEQ. ID. NOS. 7, 8, 9, 10, 11, 12, 13, 16, 30, 31, 32, 33, 34, 35, 36, 37, or may include sequences having at least 60%, preferably 70%, more preferably 80%, even more preferably 90%, yet more preferably 99% or higher sequence identity to said peptides, such peptides having neuroprotective activity.

[0048] The peptide may comprise any length of poly-arginine peptide between R8 and R22, or repeats thereof. In one embodiment, the peptide is selected from the group comprising R8, R9, R10, R11, R12, R13, R14, R15, R16, R17, and R18. In one preferred embodiment, the peptide is R10. In another preferred embodiment, the peptide is R12. In yet another preferred embodiment, the peptide is R15. In another preferred embodiment, the peptide is R18.

[0049] The use of the peptide may include the use of a mixture of any two or more of the peptides of the invention, particularly SEQ. ID. NOs 32 to 36, in the treatment or prevention of a neural injury.

[0050] In another embodiment, the use may include using the peptide of SEQ. ID. NO. 37 in the treatment or prevention of a neural injury, or the use of SEQ. ID. NO. 37 with any of the peptides of SEQ. ID. NOS. 32 to 36.

[0051] In another aspect of the invention, there is provided the isolated peptides of SEQ ID NOs 32 to 37, including sequences having at least 60%, 70%, 80%, 90%, even 99% or higher sequence identity to said peptides, such peptides having neuroprotective activity.

[0052] The peptides may be a commercially available mixture of protamine peptides isolated from salmon sperm.

[0053] As such, the peptides may be in the form of a mixture comprising protamine sulphate, as described in the European Medicines Agency "Assessment Report for Protamine containing medicinal products", Procedure no EMEA/H/A-5(3)/1341 published 15 Nov. 2012, the contents of which are incorporated herein by way of reference only.

[0054] Table 1 shows a summary of different forms of salmon sperm protamine. The protamine peptide sequences (salmon) are present in protamine sulphate for clinical use or from the SwissProt database. As used in this specification, the term "Protamine" refers to a commercially available injectable form or protamine sulphate, which comprises a mixture of the peptides of SEQ. ID. NOs 32 to 35.

[0055] The peptides may be present in the following percentage proportions in the mixture of peptides:

SEQ. ID. NO	Identifier	Percentage
32	Ptm1	15-25
33	Ptm2	27-37
34	Ptm3	20-30
35	Ptm4	15-25

[0056] In a preferred embodiment, the peptides are present in the following percentage proportions in the mixture of peptides:

SEQ. ID. NO	Identifier	Percentage
32	Ptm1	18-22
33	Ptm2	30-35
34	Ptm3	21.5-28
35	Ptm4	19-23

[0057] In a most preferred embodiment, the peptides are present in the following percentage proportions in the mixture of peptides:

SEQ. ID. NO	Identifier	Percentage
32	Ptm1	20.1
33	Ptm2	33.5
34	Ptm3	25.1
35	Ptm4	21.3

[0058] More particularly, the mixture of peptides may be a mixture of the peptides of SEQ. ID. NOs 32, 33, 34, and 35,

commercially available as protamine sulphate (Salmon), manufactured e.g. by Sanofi Aventis.

[0059] As such, the mixture of peptides may be admixed with sodium chloride, hydrochloric acid, sodium hydroxide and water.

[0060] The mixture of peptides may be in a delivery formulation that is injectable or administrable intravenously.

[0061] The peptides may be present in the delivery formulation in a concentration within a range of 0.1 mg/ml to 100 mg/ml, preferably 1 mg/ml to 20 mg/ml, most preferably 10 mg/ml.

[0062] In use, the delivery formulation, when in the form of an injectable or intravenous formulation, may be administered by slow intravenous injection over a period of between 1 and 30 minutes, preferably between 5 and 20 minutes, most preferably over a period of 10 minutes.

[0063] The peptide may have cell-penetrating activity. As such, the peptide may be a CPP.

[0064] The peptide may include repeats of arginine residues in adjacent positions, such as RR, or RRR, or RRRR, or higher order repeats, and may be interspersed between other amino acids, or between stretches of amino acids.

[0065] According to a further aspect of the invention, there is provided the use of the peptide of the invention in the manufacture of a pharmaceutical composition or medicament for the treatment of a neural injury. The invention extends to the use of mixtures of peptides of the invention in the manufacture of a medicament for the treatment of neural injury.

[0066] According to a still further aspect of the invention, there is provided the use of the peptide or pharmaceutical composition of the invention to affect the function of cell surface receptors associated with calcium influx, more specifically to interact with the NMDA, AMPA, VGCCs, NCX, TRMP2/7, ASIC and mGlu receptors, more specifically still to result in reduced cellular calcium influx. In another embodiment of the invention, there is provided the use of the peptide or pharmaceutical composition of the invention to interact with and/or stabilise the outer mitochondrial membrane and thereby help to preserve mitochondrial function. According to a still further aspect of the invention, there is provided the use of the peptide or pharmaceutical composition of the invention to inhibit, downregulate, or affect the calcium-dependent pro-protein convertase enzyme furin.

[0067] According to another aspect of the invention, there is provided a pharmaceutical composition or medicament for the treatment of a neural injury, the pharmaceutical composition or medicament including the isolated peptide of the invention, or any one or more of the isolated peptides of the invention.

[0068] The pharmaceutical composition or medicament may comprise a pharmaceutically acceptable carrier adjuvant, or vehicle

[0069] According to a still further aspect of the invention, there is provided a method of treating a neural injury, the method including the steps of administering to a patient in need thereof a pharmaceutically acceptable and/or pharmaceutically effective amount of the peptide of the invention. The patient may be administered a physiologically acceptable amount of the peptide of the invention.

[0070] According to a still further aspect of the invention there is provided a method for inhibiting neuronal cell death in a subject comprising administering to a subject in need of such treatment a neuroprotective peptide in an amount effective to inhibit neuronal cell death in the subject, where the neuroprotective peptide is any one or more of the peptides of the invention.

[0071] The patient may be administered a physiologically acceptable amount of a mixture of any two or more of the peptides of the invention.

[0072] More particularly, the patient may be administered a mixture of any two or more peptides selected from the group comprising SEQ. ID. NOs 32, 33, 34, 35, 36, or 37. In one particular aspect of the invention, the patient may be administered a mixture comprising SEQ. ID. NOs 32, 33, 34 and 35. In other combinations, the patient may be administered any combination of peptides selected from the group consisting of SEQ. ID. NOs 32, 33, 34 and 35, together with the peptide of SEQ. ID. NO. 36. In a particular embodiment, the patient may be administered SEQ. ID. NO. 35.

[0073] The peptide of the invention may provide neuroprotective activity against antagonists of neurotransmitter receptors. The neurotransmitter receptors may be receptors that are bound by, interact with, or are affected by NMDA, glutamate, kainic acid, or ischemic processes. The peptide of the invention may be included within other polypeptides or may be fused to other polypeptides. The peptide of the invention may be linked or fused at either the N- or C-termini of such other polypeptides. The peptide of the invention may be linked or fused to such other polypeptides so as to display the peptides of the invention in a conformation suitable for treating a neural injury.

[0074] Alternatively, or additionally, one or more of the peptides of the invention may be fused to one another with a linker sequence. The linker sequence may comprise any sequence of amino adds, including, but not limited to basic/cationic amino acid-rich linker sequences. Alternatively, or additionally, the linker sequences may be cleavable linkers. In one embodiment, the linker may be one or more MMP-type linkers, calpain, caspase or tPA linkers. MMP-type linkers are defined as the peptide sequence recognized and cleaved by matrix metalloproteinases (MMPs). Similarly a calpain, caspase or tPA linker is a peptide sequence recognized and cleaved by these protease enzymes (i.e. calpain, caspase or tPA, respectively). The peptides of the invention may also be fused to other peptides that are to be transported to the site of a neural injury or are to be transported intracellularly into or within neural cells.

[0075] The peptides of the invention may also be linked to ancillary peptides that can bind to or interact with enzymes detrimental to neural function, so that the ancillary peptides can function as competitive inhibitors of the enzymes following transportation across the cell membrane. The ancillary peptides may be selected from IPA, calpain, and MMP, and may be linked to the peptide of the invention using a cleavable linker such as a caspase sequence, so that the IPA, calpain or MMP may be liberated from the peptide of the invention and may then function as a competitive inhibitor intracellularly for enzymes detrimental to neural function.

[0076] As such, the invention extends to a peptide of the invention linked to a caspase cleavage site, itself in turn linked to calpain, tPA or MMP.

[0077] The peptides of the invention may exhibit neuroprotective activity at IC50 levels of less than 10 μM, preferably less than 5 μM, preferably less than 1 μM, in some cases as low as, or lower than, 0.2 μM, even as low as 0.1 μM.

[0078] As mentioned before, the peptide may include repeats of the peptide sequences of the invention, or functional fragments thereof, i.e. fragments that exhibit neuroprotective activity.

[0079] Accordingly, one aspect of the invention provides an isolated polypeptide having included therein a peptide segment exhibiting neuroprotective effects, the peptide segment being between 8 and 100 amino acid residues in length, wherein the neuroprotective peptide is selected from peptide segments having a basic/cationic amino acid content of more than 20% of the length of the peptide segment, preferably more than 30%, more than 40%, more than 50%, more than 60%, more than 70% more than 80%, more than 90, more than 95%, more than 99%, or most preferably 100%.

[0080] According to another aspect of the invention, there is provided an isolated polynucleotide sequence that encodes a peptide of the invention, sequences complementary to the isolated polynucleotide sequence, and sequences having at least 60%, 70%, 80%, 90%, 95%, 99%, or 100% homology with the isolated polynucleotide sequences. The polynucleotide sequence may be one or more isolated sequences and may be sequences that hybridize under stringent conditions with the polynucleotide sequences of the invention. The polynucleotide sequences may be non-naturally occurring polynucleotide sequences or DNA. As such, they may include man-made, artificial constructs, such as cDNA. Also included in the invention are vectors, such as expression vectors, which include the isolated foregoing isolated nucleic acids, as well as cells transformed with such vectors or DNA sequences. The polynucleotide sequence may encode protamine. The polynucleotide sequences may be the sequence of SEQ. ID. NO. 38.

[0081] In another aspect of the invention, there is provided the isolated peptides selected from the group consisting of SEQ. ID. NOS. 7, 8, 9, 10, 11, 12, 13, 16, 30, 31, 32, 33, 34, 35, 36, and 37, including sequences having at least 60%, preferably 70%, more preferably 80%, even more preferably 90%, yet more preferably 99% or higher sequence identity to said peptides, such peptides having neuroprotective activity.

[0082] The use of the isolated nucleic acids, vectors, or cells in the preparation of a pharmaceutical formulation or medicament also is provided.

[0083] The present invention furthermore provides kits comprising the abovementioned pharmaceutical composition (in one or more container(s)) in at least one of the above formulations and an instruction manual or information brochure regarding instructions and/or information with respect to application of the pharmaceutical composition.

[0084] In one embodiment, a pharmaceutical composition comprising the peptide of the invention as defined above is for use in the treatment of ischemia, Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, stroke, peripheral neuropathy, spinal cord injury or epilepsy.

[0085] In another embodiment, the present invention provides a method for promoting survival of neurons comprising the step of contacting neurons with the peptides of the invention, or combinations thereof. Preferably, the method is performed in vitro. The invention, in another aspect thereof, provides a method and composition for protecting blood brain barrier endothelial cells from OGD or ischemia.

[0086] These findings demonstrate that the peptides of the invention have the ability to, and can be used in methods to, inhibit or ameliorate neurodamaging events/pathways associated with excitotoxic and ischemic injuries. Also, as shown by the effects of protamine and protamine derivatives in pre-insult exposure trials contained herein, a new key finding was that protamine treatment of neurons 1 to 4 hours before glutamate or OGD exposure can induce a neuroprotective response by reducing cell death. This is significant because there are a number of cerebrovascular (e.g. carotid endarterectomy) and cardiovascular (e.g. coronary artery bypass graft) surgical procedures where there is a risk patients can suffer cerebral ischemia or a stroke resulting in brain injury.

[0087] Therefore, the method of the invention extends to the administering of the at least one peptide, medicament, or pharmaceutical composition of the invention in a window of 0.25 hours to 4 hours, preferably 0.5 to 3 hours, most preferably 1 to 2 hours before such a procedure to protect the brain against any such cerebral ischemic event.

[0088] The invention extends thus to the use of the at least one peptide of the invention in treating or preventing neural injury, cerebrovascular insults or injury, cardiovascular insults or injury, or surgical procedures where patients may be at risk of suffering cerebral ischemia or a stroke.

[0089] Minor modifications of the primary amino acid sequence of the sequences of the invention disclosed herein may result in proteins that have substantially equivalent or enhanced activities. These modifications may be deliberate, as through site-directed mutagenesis, or may be accidental, such as through mutation of hosts that are protamine- or LMWP-producing organisms. All of these modifications are included within the scope of the invention as long as the neuroprotective activity is retained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0090] Further features of the present invention are more fully described in the following description of several non-limiting embodiments included solely for the purposes of exemplifying the present invention. The following description is not a restriction on the broad summary, disclosure or description of the invention as set out above and is made with reference to the accompanying drawings in which the term "Protamine" or "Ptm" refers to commercially available protamine sulphate (manufactured commercially by several manufacturers, including Sanofi Averts, typically as specified in Hoffman, 1990), while "Ptm1" to "Ptm" 5 refer to SEQ. ID. NOs 32, 33, 34, 35, and 36, respectively, and in which:

[0091] FIG. **1***a* shows the results of the glutamic acid excitotoxicity model; concentration of peptide in μM. A: Neuronal viability 24 hours following glutamic acid exposure and treatment with CPPs, positive control peptides (JNKI-1D-TAT/PYC36L-TAT) and glutamate receptor blockers (Blkrs; 5 μM: MK801/5 μM: CNQX). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM, n=4-6; *P<0.05).

[0092] FIG. **1***b* shows further results of the Glutamic acid excitotoxicity model; concentration of peptide in μM. Neuronal viability 24 hours following glutamic acid exposure and treatment with TAT-L and TAT-D peptides MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM; n=4-6; *P<0.05).

[0093] FIG. **1***c* shows further results from the glutamic acid excitotoxicity model. Specifically, the efficacy of peptides when washed out prior to glutamic acid insult; concentration of peptide in μM. Neuronal viability 24 hours following glutamic acid exposure when CPPs were washed-out prior to insult. MTS data were expressed as percentage neuronal

viability with no insult control taken as 100% viability (mean±SEM; n=4-6; *P<0.05).

[0094] FIG. **1***d* shows further results from the glutamic acid excitotoxicity model. Efficacy of peptides when added after the glutamic acid insult. Neuronal viability 24 hours following glutamic acid exposure when Arg-9 and Arg-12 peptides and control peptides JNKI-1D-TAT and NR29c were added 0 or 15 minutes post-insult; in this experiment glutamic acid exposure resulted in less cell death in controls than in other experiments (60% vs 95%). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM; n=4-6, *P<0.05).

[0095] FIG. **1***e* shows further results from the glutamic acid excitotoxicity model; concentration of peptide in μM. A: Neuronal viability 24 hours following glutamic add exposure and treatment with R9, R12, R15, R18 and R9/tPA/R9. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM, n=4; *P<0.05).

[0096] FIG. **1***f* shows further results from the glutamic acid excitotoxicity model; concentration of peptide in μM. Neuronal viability 24 hours following glutamic acid exposure and treatment with R9, E9/R9, DAHK and PTD4. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM; n=4; *P<0.05).

[0097] FIG. **1***g* shows further results from the glutamic acid excitotoxicity model; concentration of peptide μM. Neuronal viability 24 hours following glutamic acid exposure and treatment with R9 and NR29c and control peptide PCY36 (PYC36L-TAT). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM; n 4; *P<0.05).

[0098] FIG. **1***h* shows further results from the glutamic acid excitotoxicity model: milder insult; concentration of peptide μM. Neuronal viability 24 hours following glutamic acid exposure and treatment with R9, R12 and NR29c and control peptide JNK (JNKI-1-TAT). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM; n=4; *P<0.05).

[0099] FIG. **1***i* shows further results from the glutamic acid excitotoxicity model: milder insult; concentration of peptide μM. Neuronal viability 24 hours following glutamic acid exposure and treatment with R1, R3, R6, R9, R12 and NR29c control peptide. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM: n=4; *P<0.05).

[0100] FIG. **1***j* shows further results from the glutamic acid excitotoxicity model; concentration of peptide=5 μM, Neuronal viability 24 hours following glutamic acid exposure and treatment with R1, R3, R9 old (Mimotopes), R9 new (China peptides), R12. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean a SEM; n=4; *P<0.05).

[0101] FIG. **2** shows the results of a kainic acid excitotoxicity model; concentration of peptide in p M. Neuronal viability 24 hours following kainic acid exposure and treatment with CPPs, positive control peptides (JNKI-1D-TAT/PYC36L-TAT) and glutamate receptor blockers (Blkrs; 5 μM: MK801/5 μM: CNQX). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM; n=4; *P<0.05).

[0102] FIG. **3***a* shows the results of an in vitro isohemia model. Peptides present during in vitro ischemia and at 50% dose after ischemia: concentration of peptide in M. Neuronal viability 24 hours following in vitro ischemia and treatment with CPPs, positive control peptide (PYC36L-TAT) and glutamate receptor blockers (Blkrs; 5 μM: MK801/5 μM: CNQX). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean SEM; n=4; *P<0.05).

[0103] FIG. **3***b* shows further results of an in vitro ischemia model. Peptides present after in vitro ischemia: concentration of peptide in μM. Neuronal viability 24 hours following in vitro ischemia and treatment with R9, R12, R15 and RIS. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SEM; n=4; *P<0.05).

[0104] FIG. **3***c* shows further results of an in vitro ischemia model. R9 peptide present during in vitro ischemia and at 50% dose after ischemia: Peptide dose for bEND3 cells was 10 μM during/5 μM post-in vitro ischemia. Peptide dose for SH-5YSY cells was 5 μM during/2.5 μM post-in vitro ischemia. Cell viability 24 hours following in vitro ischemia (MTS data mean±SEM; n=4; *P<0.05).

[0105] FIG. **4** shows neuronal viability following exposure of cultures to different peptide concentrations. Peptide concentration shown in μM. Neuronal viability 24 hours following exposure with R3, R6, R9, R12, R15, R18, JNK (JNKI-1D-TAT) and NR29c peptides. Cell viability data expressed as MTS absorbance at 490 nm (mean±SEM; n=4).

[0106] FIG. **5** shows the results of the initial animal model pilot trial, which shows the efficacy of R9D peptide in rat permanent middle cerebral artery occlusion (MCAO) stroke model. R9D peptide was administered intravenously 30 min post-MCAO. Infarct volume (brain injury) was measured 24 h post-MCAO (mean±SD).

[0107] FIG. **6** shows a dose response study using R9, R10, R11, R12, R13 and R14 in the glutamate model. Mean±SEM: N=4; * P<0.05. (Peptide concentration in μM).

[0108] FIG. **7** shows a dose response study using R9D, R13, R14 and R15 in the glutamate model Mean±SEM: N=4; * P<0.05. (Peptide concentration in μM).

[0109] FIG. **8** shows a dose response study using R6, R7, R8, and R9 in the glutamate model. Mean±SEM: N=4: * P<0.05. (Peptide concentration in μM).

[0110] FIG. **9** shows the results of the glutamic acid excitotoxicity model; concentration of protamine in μM. Treatment of neuronal cultures with protamine was for 15 minutes prior to glutamic acid exposure (100 μM), which was for 5 minutes at 37° C. Neuronal viability 24 hours following glutamic acid exposure and treatment with different protamine concentrations or no treatment (Glut control). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD, n=4-6; *P<0.05).

[0111] FIG. **10** shows the results of the glutamic acid excitotoxicity model; concentration of protamine in μM. Treatment of neuronal cultures with protamine was for 15 minutes prior to and during glutamic acid exposure (100 μM), which was for 5 minutes at 37° C. Neuronal viability 24 hours following glutamic acid exposure and treatment with different protamine concentrations or no treatment (Glut control). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4-6, *P<0.05).

[0112] FIG. **11** shows the results of the glutamic acid excitotoxicity model; concentration of protamine in μM. Treatment of neuronal cultures with protamine was for 5 or 10

minutes prior to glutamic acid exposure (100 μM), (5 minutes at 37° C.) only. Neuronal viability 24 hours following glutamic acid exposure and treatment with different protamine concentrations or no treatment (Glut). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0113] FIG. **12** shows the results of the glutamic acid excitotoxicity model; concentration of protamine and low molecular weight protamine (LMWP) in μM. Treatment of neuronal cultures with protamine or LMWP was for 15 minutes prior to and during glutamic acid exposure (100 μM), which was for 5 minutes at 37° C. Neuronal viability 24 hours following glutamic acid exposure and treatment with different protamine or LMWP concentrations or no treatment (Glut control). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0114] FIG. **13** shows the results of the glutamic acid excitotoxicity model; concentration of protamine and low molecular weight protamine (LMWP) in μM. Treatment of neuronal cultures with protamine or LMWP was for 15 minutes prior to and during glutamic acid exposure (100 μM), which was for 5 minutes at 37° C. Neuronal viability 24 hours following glutamic acid exposure and treatment with different protamine or LMWP concentrations or no treatment (Glut control). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0115] FIG. **14** shows the results of the glutamic acid excitotoxicity model; concentration of protamine and LMWP in μM. Treatment of neuronal cultures with protamine was for 10 minutes immediately before, or 1 or 2 hours before glutamic acid exposure (100 μM; 5 minutes at 37° C.) only. Neuronal viability 24 hours following glutamic acid exposure and treatment with different protamine or LMWP concentrations or no treatment (Glut Control). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n 4-6; *P<0.05).

[0116] FIG. **15** shows the results of the glutamic acid excitotoxicity model; concentration of protamine and protamine peptides 1 to 5 ("Ptm 1 to 5") in μM. Treatment of neuronal cultures with protamine and protamine peptides was for 15 minutes prior to glutamic acid exposure (100 μM), which was for 5 minutes at 37° C. Neuronal viability 24 hours following glutamic acid exposure and treatment with different protamine and protamine peptides concentrations or no treatment (Glut control). MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0117] FIG. **16** shows the results of the oxygen-glucose deprivation (OGD) model; concentration of protamine in μM. Treatment of neuronal cultures with protamine was immediately after 50 minutes of OGD and until experiment end (24 h). Neuronal viability 24 hours following OGD and treatment with different protamine concentrations or no treatment (OGD). MTS data were expressed as percentage neuronal viability with no OGD control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0118] FIG. **17** shows the results of the oxygen-glucose deprivation (OGD) model; concentration of protamine in μM. Treatment of neuronal cultures with protamine was immediately after 50 minutes of OGD and until experiment end (24 h). Neuronal viability 24 hours following OGD and treatment with different protamine concentrations or no treatment (OGD). MTS data were expressed as percentage neuronal viability with no OGD control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0119] FIG. **18** shows the results of the oxygen-glucose deprivation (OGD) model; concentration of protamine and LMWP in μM. Treatment of neuronal cultures with protamine or LMWP was for 10 minutes, 1 hour before 50 minutes of OGD. Neuronal viability 24 hours following OGD and pre-treatment with different protamine concentrations or no treatment (OGD). MTS data were expressed as percentage neuronal viability with no OGD control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0120] FIG. **19** shows the results of the oxygen-glucose deprivation (OGD) model; concentration of protamine in μM. Treatment of neuronal cultures with protamine was for 15 or 30 minutes, after 50 minutes of OGD. Neuronal viability 24 hours following OGD and post-treatment with different protamine concentrations or no treatment (OGD). MTS data were expressed as percentage neuronal viability with no OGD control taken as 100% viability (mean±SD; n 4-6; *P<0.05).

[0121] FIG. **20** shows the results of the oxygen-glucose deprivation (OGD) model; concentration of protamine and LMWP in μM. Treatment of neuronal cultures with protamine or LMWP was for 15 minutes, after 50 minutes of OGD. Neuronal viability 24 hours following OGD and post-treatment with different protamine or LMWP concentrations or no treatment (OGD). MTS data were expressed as percentage neuronal viability with no OGD control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0122] FIG. **21** shows the results of the oxygen-glucose deprivation (OGD) model; concentration of protamine and protamine peptides in μM (5 μM). Treatment of neuronal cultures with protamine was for 15 minutes, after 45 minutes of OGD. Neuronal viability 24 hours following OGD and post-treatment with different protamine and protamine peptides concentrations or no treatment (OGD). MTS data were expressed as percentage neuronal viability with no OGD control taken as 100% viability (mean±SD; n=5; *P<0.05).

[0123] FIG. **22** shows the results of the oxygen-glucose deprivation (OGD) model; concentration of protamine, protamine and low molecular weight protamine (LMWP) peptides in μM (5 μM). Treatment of neuronal cultures with protamine was for 15 minutes, after 45 minutes of OGD. Neuronal viability 24 hours following OGD and post-treatment with different protamine and protamine peptides concentrations or no treatment (OGD). MTS data were expressed as percentage neuronal viability with no OGD control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0124] FIG. **23** shows the results of the oxygen-glucose deprivation (OGD) model using brain endothelial cells (bEND 3 cells); concentration of protamine in μM. Treatment of bEND3 cultures with protamine was from 15 minutes immediately before 3 different OGD durations (2 h 15 min, 2 h 30 min and 2 h 45 min) and until experiment end (24 h). Cell viability was measured 24 hours following OGD. MTS data were expressed as percentage neuronal viability with no OGD control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0125] FIG. **24** shows the results of exposure of protamine peptides to brain endothelial cells (bEND3 cells); concentration of protamine 1 μM. Protamine peptides 1-5 (Ptm1-Ptm5), protamine sulphate (Ptm), and low molecular weight protamine (LMWP) added to bEND3 cell cultures for 15 min

immediately before OGD (2 h 30 min duration), Cell viability assessed 24 hours after OGD using MTS assay. MTS data were expressed as absorbance values at 490 mm (mean±SD; n=4-6; *P<0.05).

[0126] FIG. **25** shows the results of exposure of protamine to brain endothelial cells (bEND3 cells); concentration of protamine in μM. Treatment of bEND3 cultures with protamine was for 0.5, 1 or 2 hours. Cell viability 2 hours following protamine exposure or no treatment (Control). MTS data were expressed as absorbance values at 490 mm (mean±SD; n=4-6; *P<0.05).

[0127] FIG. **26** shows the results of exposure of protamine to brain endothelial cells (bEND3 cells); concentration of protamine in μM. Treatment of bEND3 cultures with protamine was for 2 hours. Cell viability 2 hours following protamine exposure or no treatment (Control). MTS data were expressed as absorbance values at 490 mm (mean±SD; n=4-6; *P<0.05).

[0128] FIG. **27** shows neuroprotective effects of the R12, R15, R18 and protamine (Ptm) peptides in permanent middle cerebral artery occlusion (MCAO) stroke model when administered intravenously 30 min after occlusion. Peptide dose was 1 μmol/kg (600 μl: IV) and infarct assessment was at 24 h after MCAO (mean±SE; n=8-10; *P<0.05). Animal treatments were randomized and all procedures were performed blinded to treatment.

[0129] FIG. **28** shows neuroprotective efficacy of R9, R12, R15 and R18 in the glutamate excitotoxicity model when peptides present in neuronal cultures only during 5-min glutamic acid exposure. Neuronal viability measured 20-24 h following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n 4; *P<0.05).

[0130] FIG. **29** shows neuroprotective efficacy of R9, R12, R15 and R18 in the glutamate model when peptides present in neuronal cultures for 10 min only prior to glutamic acid exposure. Neuronal viability measured 20-24 h following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4; *P<0.05).

[0131] FIG. **30** shows neuroprotective efficacy of R12 and R15 in the glutamate model when peptides present in neuronal cultures for 10 min only at 1 to 5 h before glutamic acid exposure. Neuronal viability measured 20-24 h following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4; *P<0.05).

[0132] FIG. **31** shows neuroprotective efficacy of R9, R12, R15 and RIB in the oxygen-glucose deprivation (OGD) model when peptides added to neuronal cultures immediately after OGD and removed after 15 min. Neuronal viability measured 20-24 hours following OGD. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4-6; *P<0.05).

[0133] FIG. **32** shows neuroprotective efficacy of R9, R12, R15 and R18 in the oxygen-glucose deprivation when peptides present in neuronal cultures only for 10 min at 1 to 3 h before OGD. Neuronal viability measured 20-24 hours following OGD. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n 4-6; *P<0.05).

[0134] FIG. **33** shows neuroprotective efficacy of PTD4, E9/R9 and R9 in the glutamate excitotoxicity model when peptides present in neuronal cultures for 15 min before and during 5-min glutamic acid exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n 4; *P<0.05).

[0135] FIG. **34** shows neuroprotective efficacy of XIP and PYC36-TAT in the glutamate excitotoxicity model when peptides present in neuronal cultures for 15 min before and during 5-min glutamic acid exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n 4; *P<0.05).

[0136] FIG. **35** shows neuroprotective efficacy of NCXBP3 in the glutamate excitotoxicity model when peptide present in neuronal cultures for 15 min before and during 5-min glutamic acid exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4; *P<0.05).

[0137] FIG. **36** shows neuroprotective efficacy of K10, R10 and TAT-NR2B9c in the glutamate excitotoxicity model when peptides present in neuronal cultures for 15 min before and during 5-min glutamic acid exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4; *P<0.05).

[0138] FIG. **37** shows neuroprotective efficacy of R15 and TAT-NR2B9c in the NMDA excitotoxicity model when peptides present in neuronal cultures for 15 min before and during 5-min NMDA exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in μM. MIS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4; *P<0.05).

[0139] FIG. **38** shows neuroprotective efficacy of R8 and Cal/R9 in the glutamate excitotoxicity model when peptides present in neuronal cultures for 15 min before and during 5-min glutamic acid exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in M. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4: *P<0.05).

[0140] FIG. **39** shows neuroprotective efficacy of R9D, R12, R15 and PYC36-TAT peptides incubated with ±heparin (20 IU/ml) for 5 min at room temperature before for being added to neuronal cultures for 10 min only prior to glutamic acid exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4; *P<0.05).

[0141] FIG. **40** shows neuroprotective efficacy R9D, R12, and R15 and glutamate receptor blockers (Blks: 5 μM MK801/5 μM CNQX) when neuronal cultures incubated±heparin (40 for 5 min at 37° C. before addition of

peptides for 10 min only at 37° C., and then removed prior to glutamic acid exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in μM. MIS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4; *P<0.05).

[0142] FIG. **41** shows neuroprotective efficacy of kFGF, kFGF-JNKI-1, TAT-JNKI-1 and JNKI-1TATD in the glutamate excitotoxicity model when peptides present in neuronal cultures for 15 min before and during 5-min glutamic acid exposure. Neuronal viability measured 20-24 hours following glutamic acid. Concentration of peptide in μM. MTS data were expressed as percentage neuronal viability with no insult control taken as 100% viability (mean±SD; n=4; *P<0.05).

[0143] FIG. **42** shows the results of pre-exposure of protamine sulphate (Ptm) and R18 peptides to primary rat astrocytes for 15 min prior to oxygen-glucose deprivation. Concentration of peptides 2 μM. Cell viability assessed 24 hours after OGD using MTS assay. MTS data were expressed as absorbance values at 490 mm (mean±SD; n=4-6; *P<0.05).

[0144] FIG. **43** shows the results of exposure of protamine peptides 1-5 (Ptm1-Ptm5), protamine sulphate (Ptm), and low molecular weight protamine (LMWP) to primary rat astrocytes; concentration of protamine in μM. Treatment of astryocyte cultures with protamine was for 24 hours. Cell viability 24 hours following protamine exposure or no treatment (Control). MTS data were expressed as absorbance values at 490 mm (n=4).

[0145] FIG. **44** shows intracellular calcium influx kinetics for glutamate receptor blockers (MK801/CNQX at 5 μM/5 μM), R9D, R15, PYC36-TAT, TAT, TAT-NR2B9c JNKI-1-TATD, TAT-JNKI-1, kFGF-JNKI-1 and kFGF following glutamic acid exposure in neuronal cultures. Fura-2 AM was used for intracellular calcium assessment. Representative fluorescent Fura-2 AM tracers; fluorescence intensity (FI) of neuronal cultures 30 sec before and following addition (arrow) of glutamic acid (100 μM final concentration). Peptides or glutamate receptor blockers were added to neuronal cultures for 10 min and removed (time 0) before glutamic acid. Values are mean±SE; n=3. Peptide concentration was 5 μM.

[0146] FIG. **45**. Diagrammatic representation of proposed model of arginine-rich CPPB inducing endocytic internalization of neuronal cell surface structures. Note: model applies to neuronal synaptic and extra-synaptic plasma membranes and potentially the plasma membrane of astrocytes, pericytes, brain endothelial cells, oligodentrocytes and microglia. NMDAR: N-methyl-D-aspartate receptors; AMPAR: α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptors; NCX: sodium calcium exchanger; VGCC: voltage-gated calcium channels (e.g. CaV2.2, CaV3.3); ASIC: acid-sensing ion channels; TRPM2/7: transient receptor potential cation channels 2 and 7: mGluR: metabotropic glutamate receptors; VR1: vanilloid receptor 1 or transient receptor potential cation channel subfamily V member 1; TNFR: tumor necrosis factor receptors; EAAT: excitatory amino-acid transporters; AQP4: Aquaporin 4; Trk: tropomyosin-receptor-kinase receptors.

[0147] FIGS. **46** and **47** are reference tables of the sequences described and used in this specification.

DESCRIPTION OF EMBODIMENTS

[0148] Throughout this specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising" or "includes" or "including", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

[0149] The invention relates to isolated peptides and compositions comprising isolated peptides, and uses thereof. The isolated peptides are characterized in that they can reduce the neurodegenerative effects of a neural injury or cerebrovascular ischemic event (e.g., and especially, stroke) when administered before or after the neural injury or ischemic event, Thus, administration of the compositions of the invention reduces the loss of neuronal cells that follows a neural injury or cerebrovascular ischemic event. The Applicant has now found, surprisingly, that certain polypeptides in the form of CPPs and polypeptides having contiguous stretches of basic/cationic amino acids (particularly arginine residues, but also including lysine and tryptophan residues), exhibit neuroactive or neuroprotective activity and can serve as neuroprotective agents (i.e. for treatment of neural injury) by themselves, i.e. without having to be fused to other neuroprotective agents or peptides. As such, the invention pertains to polypeptides of between 10 and 32 amino adds in length wherein between 10 and 22 of the amino acids are cationic amino acid residues (typically arginine residues), with such peptides typically having an arginine content of 30% or higher, such peptides exhibiting neuroprotective activity in established neural injury models. This includes poly-arginine peptides, as well as protamine sulphate (as mixture of protamine peptides obtained from salmon sperm), and various versions, analogues, variants, or fragments of these peptides, including protamine and Low Molecular Weight Protamine (LMWP), and mixtures thereof.

[0150] The term "amino acid" or "residue" as used herein includes any one of the twenty naturally-occurring amino acids, the D-form of any one of the naturally-occurring amino acids, non-naturally occurring amino acids, and derivatives, analogues and mimetics thereof. Any amino acid, including naturally occurring amino acids, may be purchased commercially or synthesized by methods known in the art. Examples of non-naturally-occurring amino acids include norleucine ("Nle"), norvaline ("Nve"), β-Alanine, L- or D-naphthalanine, omithine ("Om"), homoarginine (homoArg) and others well known in the peptide art, including those described in M. Bodanzsky, "Principles of Peptide Synthesis," 1st and 2nd revised ed., Springer-Verlag, New York, N.Y., 1984 and 1993, and Stewart and Young, "Solid Phase Peptide Synthesis," 2nd ed., Pierce Chemical Co., Rockford, III., 1984, both of which are incorporated herein by reference.

[0151] Common amino acids may be referred to by their full name, standard single-letter notation (IUPAC), or standard three-letter notation for example: A, Ala, alanine; C, Cys, cysteine, D, Asp, aspartic; E, Glu, glutamic acid; F, Phe, phenylalanine, G, Gly, glycine, H, His histidine; I, Ile isoleucine; K, Lys, lysine; L, Leu, leucine; M, Met, methionine; N, Mn asparagine; P, Pro, proline; Q, Gin, glutamine; R, Arg, arginine; S, Ser, serine; T, Thr, threonine; V, Val, valine; W, Trp, tryptophan, X, Hyp, hydroxyproline; Y, Tyr, tyrosine. Any and all of the amino acids in the compositions herein can be naturally occurring, synthetic, and derivatives or mimetics thereof.

[0152] As used herein, "isolated" means a peptide described herein that is not in a natural state (e.g. it is disassociated from a larger protein molecule or cellular debris in which it naturally occurs or is normally associated with), or is

a non-naturally occurring fragment of a naturally occurring protein (e.g. the peptide comprises less than 25%, preferably less than 10% and most preferably less than 5% of the naturally occurring protein). Isolated also may mean that the amino acid sequence of the peptide does not occur in nature, for example, because the sequence is modified from a naturally occurring sequence (e.g. by alteration of certain amino acids, including basic (i.e. cationic) amino acids such as arginine, tryptophan, or lysine), or because the sequence does not contain flanking amino acids which are present in nature. The term "isolated" may mean that the peptide or amino acid sequence is a man-made sequence or polypeptide and may be non-naturally occurring.

[0153] Likewise, "isolated" as used in connection with nucleic acids which encode peptides embraces all of the foregoing, e.g. the isolated nucleic acids are disassociated from adjacent nucleotides with which they are associated in nature, and can be produced recombinantly, synthetically, by purification from biological extracts, and the like. Isolated nucleic acids can contain a portion that encodes one of the foregoing peptides and another portion that codes for another peptide or protein. The isolated nucleic acids also can be labeled. The nucleic acids include codons that are preferred for animal, bacterial, plant, or fungal usage. In certain embodiments, the isolated nucleic acid is a vector, such as an expression vector, which includes a nucleic acid that encodes one of the foregoing isolated peptides. A general method for the construction of any desired DNA sequence is provided, e.g., in Brown J. et al. (1979), Methods in Enzymology, 68:109; Sambrook J, Maniatis T (1989), supra.

[0154] Non-peptide analogues of peptides, e.g., those that provide a stabilized structure or lessened biodegradation, are also contemplated. Peptide mimetic analogues can be prepared based on a selected peptide by replacement of one or more residues by non-peptide moieties, Preferably, the non-peptide moieties permit the peptide to retain its natural conformation, or stabilize a preferred, e.g., bioactive, conformation. One example of methods for preparation of non-peptide mimetic analogues from peptides is described in Nachman et al., *Regul. Pept.* 57:359-370 (1995). The term "peptide" as used herein embraces all of the foregoing.

[0155] As mentioned above, the peptide of the present invention may be composed either of naturally occurring amino acids, i.e. L-amino acids, or of D-amino acids, i.e. of an amino acid sequence comprising D-amino acids in retro-inverso order as compared to the native sequence. The term "retro-inverso" refers to an isomer of a linear peptide in which the direction of the sequence is reversed and the chirality of each amino acid residue is inverted. Thus, any sequence herein, being present in L-form is also inherently disclosed herein as a D-enantiomeric (retro-inverso) peptide sequence. D-enantiomeric (retro-inverse) peptide sequences according to the invention can be constructed, e.g. by synthesizing a reverse of the amino acid sequence for the corresponding native L-amino acid sequence. In D-retro inverse enantiomeric peptides, e.g. a component of the isolated peptide, the positions of carbonyl and amino groups in each single amide bond are exchanged, while the position of the side-chain groups at each alpha carbon is preserved.

[0156] Preparation of a component of the isolated peptides of the invention as defined above having D-enantiomeric amino acids can be achieved by chemically synthesizing a reverse amino acid sequence of the corresponding naturally occurring L-form amino acid sequence or by any other suitable method known to a skilled person. Alternatively, the D-retro-inverso-enantiomeric form of an peptide or a component thereof may be prepared using chemical synthesis as disclosed above utilizing an L-form of an peptide or a component thereof as a matrix for chemical synthesis of the D-retro-inverso-enantiomeric form.

[0157] A cationic amino acid-rich polypeptide (which can also be referred to as a cationic amino acid polymer or copolymer) can include a polypeptide or oligomer of 10 to 32 amino acids in length. As such, by "cationic-rich" is meant any peptide, oligopeptide, or polypeptide that comprises or includes, typically, more than 30% cationic residues, more than 50%, or even more than 60% In certain embodiments this may entail peptides comprising 90%, or even 100% cationic residues such as, preferably, arginine residues. Accordingly, by an arginine-rich polypeptide (which can also be referred to as an arginine amino acid polymer or copolymer) can include a polypeptide or oligomer of 10 to 32 amino acids in length. As such, by "arginine-rich" is meant any peptide, oligopeptide, or polypeptide that comprises or includes 10 or more arginine residues, or more than 30% arginine residues, more than 50%, or even more than 60%. As such, certain embodiments comprise peptides in which 100% of the amino acids are arginine residues, with suitable efficacy and low toxicity when used in the range of R10 to R18 and at pharmaceutically efficient dosages, while in other cases it refers to other peptides (such as CPPs and including protamine and LMWP) which have intermittent stretches of arginine residues. Usually, the stretches of arginine residues comprise consecutive/contiguous 4 to 5 arginine residues, being interspersed by other amino acid residues in preferred embodiments, the interspersed amino acids are lysine (K) residues, since these also have a generally cationic charge.

[0158] In certain embodiments, an arginine polymer or copolymer includes at least 11 contiguous arginine residues, more preferably at least 12 contiguous arginine residues, more preferably at least 13 contiguous arginine residues, more preferably at least 14 contiguous arginine residues, more preferably at least 15 contiguous arginine residues, more preferably at least 16 contiguous arginine residues, more preferably at least 17 contiguous arginine residues and more preferably at least 18 contiguous arginine residues. However, in certain embodiments, there may be contiguous sequences of 4 to 5 arginine residues interspersed by other, non-arginine residues, such as, those exemplified by protamine, LMWP, and functional variants thereof having neuroprotective activity or for use in treating neural injury, as shown herein. In a preferred embodiment, use is made of R15.

[0159] The contiguous arginine residues can be at the C-terminus of the polypeptide, N-terminus of the polypeptide, in the centre of the polypeptide (e.g., surrounded by non-arginine amino acid residues), or in any position within a polypeptide. Non-arginine residues are preferably amino acids, amino acid derivatives, or amino acid mimetics that do not significantly reduce the rate of membrane transport of the polymer into cells, including, for example, glycine, alanine, cysteine, valine, leucine, isoleucine, methionine, serine, threonine, α-amino-beta-guanidinopropionic acid, α-amino-γ-guanidinobutyric acid, and α-amino-ϵ-guanidinocaproic acid.

[0160] Various changes may be made including the addition of various side groups that do not affect the manner in which the peptide functions, or which favourably affect the manner in which the peptide functions. Such changes may

involve adding or subtracting charge groups, substituting amino acids, adding lipophilic moieties that dO not effect binding but that affect the overall charge characteristics of the molecule facilitating delivery across the blood-brain barrier, etc. For each such change, no more than routine experimentation is required to test whether the molecule functions according to the invention. One simply makes the desired change or selects the desired peptide and applies it in a fashion as described in detail in the examples. For example, if the peptide (modified or unmodified) is active in a test of protection against kainic acid, or if such a peptide competes with the parent neurotransmitter in a test of neurotransmitter function, then the peptide is a functional neurotransmitter peptide.

[0161] The invention also embraces functional variants of the isolated peptide. As used herein, a "functional variant" or "variant" of an isolated peptide is a peptide which contains one or more modifications to the primary amino acid sequence of the isolated peptide and retains the properties disclosed herein. Modifications which create a functional variant of the isolated peptide can be made, for example, 1) to enhance a property of an isolated peptide, such as peptide stability in an expression system; 2) to provide a novel activity or property to an isolated peptide, such as addition of an antigenic epitope or addition of a detectable moiety; or 3) to provide a different amino acid sequence that produces the same or similar peptide properties. Modifications to an isolated peptide can be made to a nucleic acid that encodes the peptide, and can include deletions, point mutations, truncations, amino acid substitutions and additions of amino acids. Alternatively, modifications can be made directly to the peptide, such as by cleavage, addition of a linker molecule, preferably a cleavable linker such as MMP, calpain, tPA, addition of a detectable moiety such as biotin, addition of a fatty acid, substitution of one amino acid for another and the like. Modifications also embrace fusion proteins comprising all or part of the isolated peptide amino acid sequence. In one embodiment, the linker is selected from one or more MMP-type linkers, calpain, caspase, or tPA linkers. MMP-type linkers are defined as the peptide sequence recognized and cleaved by matrix metalloproteinases (MMPs). Similarly a calpain, caspase or PA linker is a peptide sequence recognized and cleaved by these protease enzymes. In certain embodiments, the peptides of the invention are also fused to other peptides that are to be transported to the site of a neural injury or are to be transported intracellularly in neural cells. As such, the peptides of the invention may also be linked to ancillary peptides that can bind to or interact with enzymes detrimental to neural function, so that the ancillary peptides can function as competitive inhibitors of the enzymes following transportation across the cell membrane by the peptide of the invention. The ancillary peptides are tPA, calpain, and MMP, and are linked to the peptide of the invention using a cleavable linker such as a caspase sequence, so that the tPA, calpain or MMP is liberated from the peptide of the invention to then function as a competitive inhibitor intracellularly for enzymes detrimental to neural function.

[0162] As such, the invention extends to a peptide of the invention, such as R10-R18 or Ptm1-5 or LMWP, or variants thereof, linked to a caspase cleavage site, itself in turn linked to calpain, tPA or MMP.

[0163] The term "sequence identity" as defined herein means that the sequences are compared as follows. To determine the percent identity of two amino acid sequences, the sequences can be aligned for optimal comparison purposes (e.g., gaps can be introduced in the sequence of a first amino acid sequence). The amino acids at corresponding amino acid positions can then be compared. When a position in the first sequence is occupied by the same amino acid as the corresponding position in the second sequence, then the molecules are identical at that position. The percent identity between the two sequences is a function of the number of identical positions shared by the sequences. For example, where a particular peptide is said to have a specific percent identity to a reference polypeptide of a defined length, the percent identity is relative to the reference peptide. Thus, a peptide that is 50% identical to a reference polypeptide that is 100 amino acids long can be a 50 amino acid polypeptide that is completely identical to a 50 amino acid long portion of the reference polypeptide. It might also be a 100 amino acid long polypeptide, which is 50% identical to the reference polypeptide over its entire length. Such a determination of percent identity of two sequences can be accomplished using a mathematical algorithm. A preferred, non-limiting example of a mathematical algorithm utilized for the comparison of two sequences is the algorithm of Karlin et al. (1993), PNAS USA, 90:5873-5877. Such an algorithm is incorporated into the NBLAST program, which can be used to identify sequences having the desired identity to the amino acid sequence of the invention. To obtain gapped alignments for comparison purposes, Gapped BLAST can be utilized as described in Altschul et al., (1997), Nucleic Acids Res, 25:3389-3402. When utilizing BLAST and Gapped BLAST programs, the default parameters of the respective programs (e.g., NBLAST) can be used. The sequences further may be aligned using Version 9 of the Genetic Computing Group's GAP (global alignment program), using the default (BLOSUM62) matrix (values −4 to +11) with a gap open penalty of −12 (for the first null of a gap) and a gap extension penalty of −4 (per each additional consecutive null in the gap). After alignment, percentage identity is calculated by expressing the number of matches as a percentage of the number of amino acids in the claimed sequence. The described methods of determination of the percent identity of two amino acid sequences can be applied correspondingly to nucleic acid sequences.

[0164] The peptide of the invention may be linked directly or via a linker. A "linker" in the present context is usually a peptide, oligopeptide or polypeptide and may be used to link multiples of the peptides to one another. The peptides of the invention selected to be linked to one another can be identical sequences, or are selected from any of the peptides of the invention. A linker can have a length of 1-10 amino acids, more preferably a length of 1 to 5 amino acids and most preferably a length of 1 to 3 amino adds. In certain embodiments, the linker is not required to have any secondary structure forming properties, i.e. does not require a α-helix or β-sheet structure forming tendency, e.g. if the linker is composed of at least 35% of glycine residues. As mentioned hereinbefore, a linker can be a cleavable peptide such as an MMP peptide which can be cleaved intracellularly by normal cellular processes, effective raising the intracellular dose of the previously linked peptides, while keeping the extracellular dose low enough to not be considered toxic. The use of a(n) intracellularly/endogenously cleavable peptide, oligopeptide, or polypeptide sequence as a linker permits the peptides to separate from one another after delivery into the target cell. Cleavable oligo- or polypeptide sequences in this context also include protease cleavable oligo- or polypeptide sequences, wherein the protease cleavage site is typically selected depen-

dent on the protease endogenously expressed by the treated cell. The linker as defined above, if present as an oligo- or polypeptide sequence, can be composed either of D-amino acids or of naturally occurring amino acids, i.e. L-amino acids. As an alternative to the above, coupling or fusion of the peptides can be accomplished via a coupling or conjugating agent, e.g a cross-linking reagent. There are several intermolecular cross-linking reagents which can be utilized, see for example, Means and Feeney, Chemical Modification of Proteins, Holden-Day, 1974, pp. 39-43. Among these reagents are, for example, N-succinimidyl 3-(2-pyridyldithio)propionate (SPDP) or N,N'-(1,3-phenylene)bismaleimide; N,N'-ethylene-bis-(iodoacetamide) or other such reagent having 6 to 11 carbon methylene bridges; and 1,5-difluoro-2,4-dinitrobenzene. Other cross-linking reagents useful for this purpose include: p,p'-difluoro-m,m'-dinitrodiphenylsulfone; dimethyl adipimidate; phenol-1,4-disulfonylchloride; hexamethylenediisocyanate or diisothiocyanate, or azophenyl-p-diisocyanate; glutaraldehyde and disdiazobenzidine. Cross-linking reagents may be homobifunctional, i.e., having two functional groups that undergo the same reaction. A preferred homobifunctional cross-linking reagent is bismaleimidohexane (BMH). BMH contains two maleimide functional groups, which react specifically with sulfhydryl-containing compounds under mild conditions (pH 6.5-7.7). The two maleimide groups are connected by a hydrocarbon chain. Therefore, BMH is useful for irreversible cross-linking of proteins (or polypeptides) that contain cysteine residues. Cross-linking reagents may also be heterobifunctional. Heterobifunctional cross-linking reagents have two different functional groups, for example an amine-reactive group and a thiol-reactive group, that will cross-link two proteins having free amines and thiols, respectively. Examples of heterobifunctional cross-linking reagents are succinimidyl 4-(N-maleimidomethyl)cyclohexane-1-carboxylate (SMCC), m-maleimidobenzoyl-N-hydroxysuccinimide ester (MBS), and succinimide 4-(p-maleimidophenyl)butyrate (SMPB), an extended chain analogue of MBS. The succinimidyl group of these cross-linking reagents with a primary amine, and the thiol-reactive maleimide forms a covalent bond with the thiol of a cysteine residue. Because cross-linking reagents often have low solubility in water, a hydrophilic moiety, such as a sultanate group, may be added to the cross-linking reagent to improve its water solubility. Sulfo-MBS and sulfo-SMCC are examples of cross-linking reagents modified for water solubility. Many cross-linking reagents yield a conjugate that is essentially non-cleavable under cellular conditions. Therefore, some cross-linking reagents contain a covalent bond, such as a disulfide, that is cleavable under cellular conditions. For example, Traut's reagent, dithiobis (succinimidylpropionate) (DSP), and N-succinimidyl 3-(2-pyridyldithio)propionate (SPDP) are well-known cleavable cross-linkers. The use of a cleavable cross-linking reagent permits the peptides to be separated after delivery into the target cell, if desired, provided the cell is capable of cleaving a particular sequence of the crosslinker reagent. For this purpose, direct disulfide linkage may also be useful. Chemical cross-linking may also include the use of spacer arms. Spacer arms provide intramolecular flexibility or adjust intramolecular distances between conjugated moieties and thereby may help preserve biological activity. A spacer arm may be in the form of a protein (or polypeptide) moiety that includes spacer amino acids, e.g. proline. Alternatively, a spacer arm may be part of the cross-linking reagent, such as in "long-chain SPDP" (Pierce Chem. Co., Rockford, Ill., cat. No. 21651H). Numerous cross-linking reagents, including the ones discussed above, are commercially available. Detailed instructions for their use are readily available from the commercial suppliers. A general reference on protein cross-linking and conjugate preparation is: Wong, Chemistry of Protein Conjugation and Cross-Linking, CRC Press (1991).

[0165] The peptides of the invention may also contain a "derivative", "variant", or "functional fragment", i.e. a sequence of a peptide that is derived from the naturally occurring (L-amino-acid) sequence of a peptide of the invention as defined above by way of substitution(s) of one or more amino acids at one or more of sites of the amino acid sequence, by way of deletion(s) of one or more amino acids at any site of the naturally occurring sequence, and/or by way of insertion (s) of one or more amino acids at one or more sites of the naturally occurring peptide sequence. "Derivatives" shall retain their biological activity if used as peptides of the invention, e.g. a derivative of any of the peptides of the invention shall retain its neuroprotective activity. Derivatives in the context of the present invention may also occur in the form of their L- or D-amino-acid sequences as defined above, or both.

[0166] If substitution(s) of amino acid(s) are carried out for the preparation of a derivative of the peptides of the invention, conservative (amino acid) substitutions are preferred. Conservative (amino acid) substitutions typically include substitutions within the following groups: glycine and alanine; valine, isoleucine and leucine; aspartic acid and glutamic acid; asparagine and glutamine; serine and threonine; lysine and arginine; and phenylalanine and tyrosine. Thus, preferred conservative substitution groups are aspartate-glutamate; asparagine-glutamine; valine-leucine-isoleucine; alanine-valine; and phenylalanine-tyrosine. By such mutations e.g. stability and/or effectiveness of a peptide may be enhanced. If mutations are introduced into the peptide, the peptide remains (functionally) homologous, e.g. in sequence, in function, and in antigenic character or other function. Such mutated components of the peptide can possess altered properties that may be advantageous over the non-altered sequences of the peptides of the invention for certain applications (e.g. increased pH optimum, increased temperature stability etc.).

[0167] A derivative of the peptide of the invention is defined as having substantial identity with the non-modified sequences of the peptide of the invention. Particularly preferred are amino acid sequences which have at least 30% sequence identity, preferably at least 50% sequence identity, even preferably at least 60% sequence identity, even preferably at least 75% sequence identity, even more preferably at least 80%, yet more preferably 90% sequence identity and most preferably at least 95% or even 99% sequence identity to the naturally occurring analogue. Appropriate methods for synthesis or isolation of a functional derivative of the peptides of the invention as well as for determination of percent identity of two amino acid sequences are described above. Additionally, methods for production of derivatives of the peptides as disclosed above are well known and can be carried out following standard methods which are well known by a person skilled in the art (see e.g., Sambrook J, Maniatis T (1989)).

[0168] As a further embodiment, the invention provides pharmaceutical compositions or medicaments comprising the peptides as defined herein. In certain embodiments, such pharmaceutical compositions or medicaments comprise the peptides as well as an optional linker, as defined herein.

Additionally, such a pharmaceutical composition or medicament can comprise a pharmaceutically acceptable carrier, adjuvant, or vehicle. A "pharmaceutically acceptable carrier, adjuvant, or vehicle" according to the invention refers to a non-toxic carrier, adjuvant or vehicle that does not destroy the pharmacological activity or physiological targeting of the peptide with which it is formulated. Pharmaceutically acceptable carriers, adjuvants or vehicles that can be used in the pharmaceutical compositions of this invention include, but are not limited to those that can be applied cranially or intracranially, or that can cross the blood-brain barrier (BBB). Notwithstanding this, the pharmaceutical compositions of the invention can include ion exchangers, alumina, aluminum stearate, lecithin, serum proteins, such as human serum albumin, buffer substances such as phosphates, glycine, sorbic acid, potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, water, salts or electrolytes, such as disodium hydrogen phosphate, potassium hydrogen phosphate, sodium chloride, zinc salts, colloidal silica, magnesium trisilicate, polyvinyl pyrrolidone, cellulose-based substances, polyethylene glycol, sodium carboxymethylcellulose, polyacrylates, waxes, polyethylene-polyoxypropylene-block polymers, polyethylene glycol and wool fat.

[0169] The pharmaceutical compositions of the present invention may be administered orally, parenterally, by inhalation spray, topically, rectally, nasally, buccally, vaginally, cerebrally, or via an implanted reservoir.

[0170] The term parenteral as used herein includes subcutaneous, intravenous, intramuscular, intra-articular, intrasynovial, intrasternal, intrathecal, intrahepatic, intralesional and intracranial injection or infusion techniques. The pharmaceutical compositions are administered orally, intraperitoneally or intravenously. Sterile injectable forms of the pharmaceutical compositions of this invention may be aqueous or oleaginous suspension. These suspensions can be formulated according to techniques known in the art using suitable dispersing or wetting agents and suspending agents. The sterile injectable preparation can also be a sterile injectable solution or suspension in a non-toxic parenterally-acceptable diluent or solvent, for example as a solution in 1,3-butanediol. Among the acceptable vehicles and solvents that may be employed are water, Ringer's solution and isotonic sodium chloride solution. In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium.

[0171] As such, any bland fixed oil may be employed including synthetic mono- or di-glycerides. Fatty acids, such as oleic acid and its glyceride derivatives are useful in the preparation of injectables, as are natural pharmaceutically-acceptable oils, such as olive oil or castor oil, especially in their polyoxyethylated versions. These oil solutions or suspensions may also contain a long-chain alcohol diluent or dispersant, such as carboxymethyl cellulose or similar dispersing agents that are commonly used in the formulation of pharmaceutically acceptable dosage forms including emulsions and suspensions. Other commonly used surfactants, such as Tweens, Spans and other emulsifying agents or bioavailability enhancers which are commonly used in the manufacture of pharmaceutically acceptable solid, liquid, or other dosage forms may also be used for the purposes of formulation.

[0172] The pharmaceutically acceptable compositions herein may be orally administered in any orally acceptable dosage form including, but not limited to, capsules, tablets, aqueous suspensions or solutions. In the case of tablets for oral use, carriers commonly used include lactose and corn starch. Lubricating agents, such as magnesium stearate, are also typically added. For oral administration in a capsule form, useful diluents include lactose and dried cornstarch. When aqueous suspensions are required for oral use, the active ingredient is combined with emulsifying and suspending agents. If desired, certain sweetening, flavouring or colouring agents may also be added.

[0173] Alternatively, the pharmaceutical composition as defined herein may be administered in the form of suppository for rectal administration. Such a suppository can be prepared by mixing the agent with a suitable non-irritating excipient that is solid at room temperature but liquid at rectal temperature and, therefore, will melt in the rectum to release the drug. Such materials include cocoa butter, beeswax and polyethylene glycols.

[0174] The pharmaceutical composition as defined herein may also be administered topically, especially when the target of treatment includes areas or organs readily accessible by topical application, including diseases of the brain, other intra-cranial tissues, the eye, or the skin. Suitable formulations are readily prepared for each of these areas or organs.

[0175] For topical applications, the pharmaceutical composition as defined herein may be formulated in a suitable ointment containing the peptides as identified herein, suspended or dissolved in one or more carriers. Carriers for topical administration of the peptide include, but are not limited to, mineral oil, liquid petrolatum, white petrolatum, propylene glycol, polyoxyethylene, polyoxypropylene compound, emulsifying wax and water. Alternatively, the pharmaceutical composition as defined herein can be formulated in a suitable lotion or cream containing the peptide suspended or dissolved in one or more pharmaceutically acceptable carriers. Suitable carriers include, but are not limited to, mineral oil, sorbitan moNOstearate, polysorbate 60, cetyl esters wax, cetearyl alcohol, 2-octyldodecanol, benzyl alcohol and water.

[0176] The pharmaceutical composition as defined herein may also be administered by nasal aerosol or inhalation. Such a composition may be prepared according to techniques well-known in the art of pharmaceutical formulation and may be prepared as solutions in saline, employing benzyl alcohol or other suitable preservatives, absorption promoters to enhance bioavailability, fluorocarbons, and/or other conventional solubilizing or dispersing agents. The pharmaceutically acceptable composition or medicament herein is formulated for oral or parenteral administration, e.g. by injection.

[0177] For treatment purposes, a non-toxic, damage-reducing, effective amount of the peptide may be used for preparation of a pharmaceutical composition as defined above. Therefore, an amount of the peptide may be combined with the carrier material(s) to produce a composition as defined above. The pharmaceutical composition is typically prepared in a single (or multiple) dosage form, which will vary depending upon the host treated and the particular mode of administration. Usually, the pharmaceutical composition is formulated so that a dosage range per dose of 0.0001 to 100 mg/kg body weight/day of the peptide can be administered to a patient receiving the pharmaceutical composition. Preferred dosage ranges per dose vary from 0.01 mg/kg body weight/day to 50 mg/kg body weight/day, even further preferred dosage ranges per dose range from 0.1 mg/kg body weight/day to 10 mg/kg body weight/day. However, dosage ranges and treatment regimens as mentioned above may be adapted

suitably for any particular patient dependent upon a variety of factors, including the activity of the specific peptide employed, the age, body weight, general health, sex, diet, time of administration, rate of excretion, drug combination, the judgment of the treating physician and the severity of the particular disease being treated. In this context, administration may be carried with in an initial dosage range, which may be varied over the time of treatment, e.g. by increasing or decreasing the initial dosage range within the range as set forth above. Alternatively, administration may be carried out in a continuous manner by administering a specific dosage range, thereby maintaining the initial dosage range over the entire time of treatment. Both administration forms may furthermore be combined, e.g. if the dosage range is to be adapted (increased or decreased) between various sessions of the treatment but kept constant within the single session so that dosage ranges of the various sessions differ from each other.

[0178] The pharmaceutical composition and/or the peptide of the invention can be used for treatment, amelioration or prevention of diseases related to the damaging effect of an injury to cells, particularly mammalian cells, as disclosed herein, particularly for the treatment of neural injuries, including cerebral stroke or spinal cord injuries, epilepsy, perinatal hypoxia-ischemia, ischemic or traumatic injuries to the brain or spinal cord and damages to central nervous system (CNS) neurons including, without being limited thereto, acute CNS injuries, ischemic cerebral stroke or spinal cord injuries, as well as of anoxia, ischemia, mechanical injury, neuropathic pain, excitotoxicity, and related injuries. Furthermore, the pharmaceutical composition and peptides of the invention can be employed for providing a neuroactive or neuroprotective effect against, or treatment of, excitotoxic and ischemic injury, excitotoxicity, lack of neurotrophic support, disconnection, damage to neurons including e.g. epilepsy, chronic neurodegenerative conditions, and the like. In this context, excitotoxicity may be particularly involved in stroke, traumatic brain injury and neurodegenerative diseases of the central nervous system (CNS) such as Multiple sclerosis (MS), Alzheimer's disease (AD), Amyotrophic lateral sclerosis (ALS), neuropathic pain, Fibromyalgia, Parkinson's disease (PD), perinatal hypoxia-ischemia, and Huntington's disease, that can be treated herein. Other common conditions that cause excessive glutamate concentrations around neurons and which may be treated herein are hypoglycemia, vasospasm, benzodiazepine withdrawal and status epilepticus, glaucoma/deterioration of retinal ganglion cells, and the like.

[0179] The treatment, amelioration or prevention of diseases related to the damaging effect of an injury to mammalian cells as defined above as well as to further diseases or disorders as mentioned herein is typically carried out by administering a pharmaceutical composition or peptide or mixture of peptides of the invention in a dosage range as described herein. Administration of the pharmaceutical composition or peptides may be carried out either prior to onset of excitotoxicity and/or (ischemic) brain damage, i.e. the damaging effect of an injury to mammalian cells, or concurrent or subsequent thereto; for example, administration of the pharmaceutical composition or peptides may be carried out within a time of (up to) 1 hour (0-1 hours), up to 2 hours, up to 3-5 hours or up to 24 hours or more subsequent to a cerebral stroke or spinal cord injuries, ischemic or traumatic injuries to the brain or spinal cord and, in general, damages to the central nervous system (CNS) neurons. In chronic neurodegenerative disorders (AD, PD, ALS, MS, etc.) treatment may require life-long daily treatment.

[0180] When used therapeutically, the compounds of the invention are administered in therapeutically effective amounts. In general, a therapeutically effective amount means an amount necessary to delay the onset of, inhibit the progression of, or halt altogether the particular condition being treated. Therapeutically effective amounts specifically will be those that desirably influence the survival of neurons following stroke or other cerebral ischemic insult. Generally, a therapeutically effective amount will vary with the subject's age and condition, as well as the nature and extent of the disease in the subject, all of which can be determined by one of ordinary skill in the art. The dosage may be adjusted by the individual physician, particularly in the event of any complications being experienced.

[0181] As mentioned above, one aspect of the invention relates to nucleic acid sequences and their derivatives which code for an isolated peptide or variant thereof and other nucleic acid sequences which hybridize to a nucleic acid molecule consisting of the above described nucleotide sequences, under stringent conditions. The term "stringent conditions" as used herein refers to parameters with which the art is familiar. Nucleic acid hybridization parameters may be found in references which compile such methods, e.g. *Molecular Cloning: A Laboratory Manual*, J. Sambrook, et al., eds., Second Edition, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1989, or *Current Protocols in Molecular Biology*, F. M. Ausubel, et al., eds., John Wiley & Sons, inc., New York. More specifically, stringent conditions, as used herein, refers to hybridization at 65° C. in hybridization buffer (3.5×SSC, 0.02% Ficoll, 0.02% Polyvinyl pyrrolidone, 0.02% Bovine Serum Albumin, 25 mMNaH_2PO_4 (pH7), 0.5% SDS, 2 mM EDTA). SSC is 0.15 M Sodium Chloride/0.15 M Sodium Citrate, pH 7; SDS is Sodium Dodecyl Sulphate; and EDTA is Ethylene diaminetetraacetic acid. After hybridization, the membrane upon which the DNA is transferred is washed at 2×SSC at room temperature and then at 0.1×SSC/0.1×SDS at 65° C.

[0182] The present invention furthermore provides kits comprising the abovementioned pharmaceutical composition (in one or more containers) in at least one of the above formulations and an instruction manual or information brochure regarding instructions and/or information with respect to application of the pharmaceutical composition.

[0183] Throughout this specification, unless specifically stated otherwise or the context requires otherwise, reference to a single step, composition of matter, group of steps or group of compositions of matter shall be taken to encompass one and a plurality (i.e. one or more) of those steps, compositions of matter, groups of steps or group of compositions of matter.

[0184] Those skilled in the field of the invention will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. It is to be understood that the invention includes all such functional variations and modifications. The invention also includes all of the steps, features, compositions and compounds referred to or indicated in this specification, individually or collectively, and any and all combinations or any two or more of said steps or features. The present invention is not to be limited in scope by the specific embodiments described herein, which are intended for the purpose of exemplification only. Functionally-equivalent products, composi-

tions and methods are clearly within the scope of the invention, as described herein. Furthermore, the present invention is performed without undue experimentation using, unless otherwise indicated, conventional techniques of molecular biology, microbiology, neurobiology, virology, recombinant DNA technology, peptide synthesis in solution, solid phase peptide synthesis, and immunology, or techniques cited herein.

[0185] The Applicant has found, surprisingly, that certain CPPs, especially arginine rich peptides exhibit neuroprotective efficacy without the traditional requirement for being fused to previously identified neuroprotective peptides. Certain of these CPPs also exhibit low toxicity and are functional at low doses or concentrations. These CPPs include penetratin and Pep-1. More surprisingly, however, the Applicant has also found that long stretches of basic (i.e. cationic) amino acids such as polyarginine peptides of between 10 and 20 residues (inclusive) in length, preferably 10 to 18 residues (inclusive) in length, and certain peptides containing more than 10 arginine residues, such as protamine or LMWP, exhibit greatly enhanced neuroprotective activity when compared to these CPPs, and especially when compared at similar concentrations to shorter arginine-rich sequences such as R1 to R8. In particular, R12, R15, R18, when assayed in glutamic acid and or in vitro ischemia injury models, provided enhanced neuroprotection when compared to the CPPs mentioned above. The two different neuronal injury models are likely to activate different damaging cellular pathways and thereby will provide further insight into the neuroprotective spectrum and possible mode of action of the peptides of the invention.

[0186] In this specification, the abbreviation "Arg" followed by an integer indicates the number of arginine repeats in a peptide. Thus, Arg-15 (abbreviated as R15, following the IUPAC single letter abbreviation for arginine) refers to consecutive arginine residues in a peptide formation. As far as practicable, however, this specification will refer to the single letter amino acid code, i.e. R15, instead of Arg-15, for example.

Neuronal Disorders Involving Neuron Cell Death

[0187] Neuronal disorders such as migraine, stroke, traumatic brain injury, spinal cord injury epilepsy, perinatal hypoxia-ischemia and neurodegenerative disorders including Huntington's Disease (HD), Parkinson's Disease (PD), Alzheimer's Disease (AD) and Amyotrophic Lateral Sclerosis (ALS) are major causes of morbidity and disability arising from long term brain injury. The brain injuries generally involve a range of cell death processes including apoptosis, autophagy, necroptosis and necrosis, and affect neurons astrocytes, oligodentrocytes, microglia and vascular endothelial cells (collectively referred to as the neurovascular unit; NVU). The damaging triggers involved in neural injury involve diverse pathways involving glutamate excitotoxicity calcium overload, oxidative stress, proteolytic enzymes and mitochondrial disturbances. As used herein, the term "stroke" includes any ischemic disorder affecting the brain or spinal cord, e.g. thrombo-embolic occlusion in a brain or spinal cord artery, severe hypotension, perinatal hypoxia-ischaemia, a myocardial infarction, hypoxia, cerebral haemorrhage, vasospasm, a peripheral vascular disorder, a venous thrombosis, a pulmonary embolus, a transient ischaemic attack, lung ischemia, unstable angina, a reversible ischemic neurological deficit, adjunct thrombolytic activity, excessive clotting conditions, cerebral reperfusion injury, sickle cell anemia, a stroke disorder or an iatrogenically induced ischemic period such as angioplasty, or cerebral ischemia.

[0188] Increased extracellular levels of the neurotransmitter glutamate can cause neuronal cell death via acute and delayed damaging processed caused by excitotoxicity. An accumulation of extracellular glutamate over-stimulates NMDA and AMPA receptors and subsequently, VGCCs, NCX, TRMP2/7, ASIC and mGlu receptors resulting in an influx of extracellular calcium and sodium ions and the release of bound calcium from intracellular stores. Over-activation of NMDA receptors can also trigger the production of damaging molecules (e.g. nitric oxide, CLCA1, calcium-activated chloride channel regulator 1, calpain, SREBP1: sterol regulatory element binding protein-1) and signaling pathways (e.g. DAPK, death-associated protein kinase, CamKII: calcium-calmodulin-dependent protein kinase II). The increase in intracellular calcium initiates a range of cell damaging events involving phospholipases, proteases, phosphatases, kinases and nitric oxide synthase, as well as the activation of pathways triggering cell death (i.e. apoptosis, autophagy, necroptosis and necrosis).

[0189] Since the peptides of the invention are shown herein to protect neurons from death, the disclosures contained in WO2009133247 and EP 1969003 show that the peptides of the invention also find application in the treatment and/or prevention of Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, stroke, peripheral neuropathy, or epilepsy and accordingly to other associated pathologies described herein. Accordingly, the present invention is directed to a method for treatment of Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, stroke, peripheral neuropathy, epilepsy, spinal cord injury, diabetes or drug addiction, wherein a pharmaceutically effective amount of any one or more of the peptides of the invention is administered to a patient. In other words, the peptides according to the present invention are for use in the treatment of injuries associated with ischernia, as well as Alzheimer's disease (AD), Huntington's disease (HD), Parkinson's disease (PD), multiple sclerosis (MS), acute disseminated encephalomyelitis (ADEM), amyotrophic lateral sclerosis (ALS), stroke, peripheral neuropathy, epilepsy, spinal cord injury and other related pathologies described herein.

[0190] In pharmaceutical applications, the peptides can also be entrapped in microcapsules prepared, for example, by co-acervation techniques or by interfacial polymerization (for example, hydroxymethylcellulose or gelatin-microcapsules and poly-(methylmethacylate) microcapsules, respectively), in colloidal drug delivery systems (for example, liposomes, albumin microspheres, microemulsions, nanoparticles, and nanocapsules), or in macroemulsions. Such techniques are disclosed in Remington's Pharmaceutical Sciences. This may also be accomplished using sustained-release preparations. Suitable examples of sustained-release preparations include semipermeable matrices of solid hydrophobic polymers containing the peptide, which matrices are in the form of shaped articles, e.g., films, or microcapsules. Examples of sustained-release matrices include polyesters, hydrogels as described by Langer et al., J. Biomed. Mater. Res., 15: 167-277 (1981) and Langer, Chem. Tech., 12:98-105 (1982) or polyvinylalcohol, polylactides (U.S. Pat. No. 3,773,919, EP 58,481), or non-degradable ethylene-vinyl acetate.

[0191] In one embodiment, a pharmaceutical composition comprising the peptide of the invention as defined above is for use in the treatment of ischemic injury, Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis, stroke, peripheral neuropathy, or epilepsy. In another embodiment, the present invention provides a method for promoting survival of neurons comprising the step of contacting neurons with the peptides of the invention, or combinations thereof. The method can be performed in vitro as is shown herein.

[0192] The publications and other materials used herein to illuminate the background of the invention, and in particular, to provide additional details with respect to its practice, are incorporated herein by reference. The present invention is further described in the following examples, which are not intended to limit the scope of the invention.

Examples (Poly-Arginine and Arginine-Rich and Arginine-Rich Protamine Peptides of Tables 1, 2 and 5 Below).

Protamine Sulphate, Protamine Peptides and Other Peptides

[0193] Peptides listed in Table 5. Protamine sulphate (protamine; Ptm) was obtained from Sanofi Aventis. Low molecular weight protamine (LMWP) was synthesised by Mimotopes Pty Ltd (Australia). Protamine peptides 1-5 (Ptm1, Ptm2, Ptm3, Ptm4, Ptm5) were synthesised by Pepmic Co Ltd (China), The peptides were HPLC purified to greater than 90-98%. All peptides were prepared as 100× stocks (500 μM) in normal saline and assessed in a concentration range from 0.1-10 μM, dependent upon injury model.

[0194] It should be noted that protamine sulphate (protamine; Ptm) is a mixture of Ptm1-Ptm4[1]. The protamine peptides (Ptm, Ptm1-5, LMWP) are arginine rich.

Methods (Poly-Arginine and Arginine-Rich Peptides)

Primary Neuronal Cortical Cultures

[0195] Establishment of cortical cultures was as previously described (Meloni et al. 2001). Briefly, cortical tissue from E18-E19 Sprague-Dawley rats was dissociated in Dulbecco's modified Eagle medium (DMEM; Invitrogen, Australia) supplemented with 1.3 mM L-cysteine, 0.9 mM $NaHCO_a$, 10 units/ml papain (Sigma, USA) and 50 units/ml DNase (Sigma) and washed in cold DMEM/10% horse serum. Neurons were resuspended in Neurobasal (Invitrogen) containing 2% B27 supplement (B27; Invitrogen). Before seeding, 96-well sized glass wells (6 mm diameter, ProTech, Australia) or 96-well plastic plates (ProSciTech, Australia) were coated with poly-D-lysine overnight (50 ml/well: 50 mg/mL; 70-150 K, Sigma). Excess poly-D-lysine solution was then removed and replaced with Neurobasal (containing 2% B27; 4% fetal bovine serum; 1% horse serum; 62.5 mM glutamate; 25 mM 2-mercaptoethanol; and 30 mg/mL streptomycin and 30 mg/mL penicillin). Neurons were plated to obtain ≈10,000 viable neurons for each well on day in vitro 11-12. Neuronal cultures were maintained in a CO_2 incubator (5% CO_2, 95% air balance, 98% humidity) at 37° C. On day in vitro 4 one third of the culture medium was removed and replaced with fresh Neurobasal/2% B27 containing the mitotic inhibitor, cytosine arabinofuraNOside (1 mM final concentration; Sigma). On day in vitro 8 one half of the culture medium was replaced with Neurobasal/2% B27. Cultures were used on day in vitro 11 or 12 after which time they routinely consist of >97% neurons and 1-3% astrocytes (Meloni et al. 2001).

Other Cell Lines Used

[0196] A brain endothelial cell line (bEND3) and a neuroblastoma cell line (SH-SY5Y) were also used for some experiments. bEND3 and SH-SY5Y cells were cultured using standard techniques in DMEM plus 5 or 15% foetal calf serum. Rat primary astrocytes were obtained and cultured as described for cortical neurons except DMEM plus 10% foetal calf serum was used instead of Neurobasal/2% B27, and the mitotic inhibitor, cytosine arabinofuraNOside was not used.

Cell Penetrating Peptides and Control Peptides

[0197] Peptides listed in Table 1 were synthesised by Mimotopes Pty Ltd (Australia), except TAT-L, which was synthesised by Pepscan Presto (The Netherlands), and R9/tPA/R9, NCXBP3 and R9/X7/R9, which were synthesised by China Peptide Co., Ltd. Peptides listed in Table 2 were synthesised by China Peptides (China). The peptides were HPLC purified to greater than 88-96%. TAT-L, penetratin, R9 and Pep-1 were synthesised in the L-isoform and TAT-D and Arg9-D in the protease resistant D-retro-inverso form, synthesised from D-amino acids in reverse sequence (referred to as D-isoform hereafter) (Brugidou et al. 1995) (Table 1). A TAT-fused JNK inhibitory peptide (JNKI-1D-TAT) in the D-isoform and a TAT-fused AP-1 inhibitory peptide (PYC36L-TAT) in the L-isoform were used as positive controls (Table 1; Borsello et al. 2003; Meade et al. 2010b). All peptides were prepared as 100× stocks (500 μM) in normal saline and assessed in a concentration range from 0.1-15 μM, dependent upon injury model. The TAT-L peptide was only used in the glutamic acid excitotoxicity model.

TABLE 1

Amino acid sequences, molecular weights and charge of peptides

Peptide	SEQ ID NO.	Sequence	No. amino acids/No. arginine residues: molecular weight (Da)	Net charge at pH 7	Physical-chemical properties
R1: Arg-1	1	H-R-OH	1/1: 174	1	Cationic
R3: Arg-3	2	H-RRR-OH	3/3: 487	3	Cationic
R6: Arg-6	3	H-RRRRRR-OH	6/6: 955	6	Cationic
R7: Arg-7	4	H-RRRRRRR-OH	7/7: 1,111	7	Cationic

TABLE 1-continued

Amino acid sequences, molecular weights and charge of peptides

Peptide	SEQ ID NO.	Sequence	No. amino acids/No. arginine residues: molecular weight (Da)	Net charge at pH 7	Physical-chemical properties
R8: Arg-8	5	H-RRRRRRRR-OH	8/8: 1,267	8	Cationic
R9: Arg-9	6	H-RRRRRRRRR-OH	9/9: 1,424	9	Cationic
R10; Arg-10	7	H-RRRRRRRRRR-OH	10/10: 1,580	10	Cationic
R11: Arg-11	8	H-RRRRRRRRRRR-OH	11/11: 1,736	11	Cationic
R12: Arg-12	9	H-RRRRRRRRRRRR-OH	12/12: 1,892	12	Cationic
R13: Arg-13	10	H-RRRRRRRRRRRRR-OH	13/13: 2,048	13	Cationic
R14: Arg-14	11	H-RRRRRRRRRRRRRR-OH	14/14: 2,204	14	Cationic
R15: Arg-15	12	H-RRRRRRRRRRRRRRR-OH	15/15: 2,360	15	Cationic
R18: Arg-18	13	H-RRRRRRRRRRRRRRRRRR-OH	18/18: 2,829	18	Cationic
PTD-4[a]	14	H-YARAAARQARA-OH	11/3: 1,204	3	Cationic
E9/R9 (R9/E9)	15	H-EEEEEEEEE-RRRRRRRRR-OH	18/9: 2,586	0	Neutral
R9/tPA/R9 or R9/X7/R9	16	H-RRRRRRRRR-PGRVVGG-RRRRRRRRR-OH	25/19: 3,452	19	Cationic
DAHK	17	H-DAHK-OH	4/0: 469.5	0.1	NIA
NR2B9c-TAT[b]	18	H-GRKKRRQRRR-KLSSIESDV-NH2	19/6: 2,355		Cationic
D-R9	19	H-rrrrrrrrr-NH2	9/9: 1423.73	10	Cationic
TAT-D	20	H-GrrqrrkkrG-NH2	10/6: 1,453	9	Cationic
TAT-L	21	Ac-GRKKRRQRRRG-NH2	10/6: 1,494	8	Cationic
Penetratin	22	H-RQIKIWFQNRRMKWKK-NH2	16/3: 2,246	7	Cationic
Pep-1	23	H-KETWWETWWTEWSQPK KKRKV-NH2	21/1: 2,847	4	Amphiphilic
PYC36L-TAT[c]	24	H-GRKKRRQRRR-GGLQGRRRQGYQSIKP-NH2	26/10: 3,180	13	Cationic
JNKI-1D-TAT[d]	25	H-tdqsrpvqpflnlttprkprpp-rrrqrrkkrG-NH2	32/: 3,925	12	Cationic
TAT-JNKI-1[d]	26	H-GRKKRRQRRR-PPRPKRPTTLNLFPQVPRSQD T-OH	32/9: 3,924.6	11	Cationic
kFGF-JNKI-1	27	H-AAVALLPAVLLALLAP-PPRPKRPTTLNLFPQVPRSQD T-OH	38/3: 4,043.9	3	Hydrophobic
kFGF	28	H-AAVALLPAVLLALLAP-OH	16/0: 1515.96	0	Hydrophobic

TABLE 1-continued

Amino acid sequences, molecular weights and charge of peptides

Peptide	SEQ ID NO.	Sequence	No. amino acids/No. arginine residues: molecular weight (Da)	Net charge at pH 7	Physical-chemical properties
XIP[e]	29	H-RRLLFYKYVYKRYRAGKQ RG-OH	20/5: 2621.14	8	Cationic
NCXBP3[f]	30	H-RRERRRRSCAGCSRARGS CRSCRR-NH2	24/11: 2881.34	10.8	Cationic
Cal/R9	31	Ac-PLFAE-RRRRRRRRR-NH2	15/9: 2022.41	8	Cationic

At the N-terminus, H indicates free amine, and Ac indicates acetyl. At the C-terminus OH indicates free acid and NH2 indicates amide. AA = amino acids. Lower case single letter code indicates D-isoform of the amino acid. [a]Peptide describe in Ho et al (2001), [b]NR2B9c-TAT also known as NA-1 (Aarts et al., 2002; Hill et al 2012), [c]peptide described in Meade et al. 2010ab and isolated by Phylogical Ltd, [d]peptide described in Borsello et al. 2003, [e]XIP described by He et al., 1997, [f]peptide isolated by Jane Cross/Bruno Meloni from phylorner library (Phylogica Pty Ltd).

Glutamic Acid and Kainic Acid and NMDA Excitotoxicity Models and Peptide Incubation

[0198] Peptides were added to culture wells (96-well plate format) 15 minutes prior to glutamic acid or kainic acid exposure by removing media and adding 50 μl of Neurobasal/2% 327 containing CPPs, control peptides or MK801/CNQX. To induce excitotoxicity, 50 μl of Neurobasal/2% B27 containing glutamic acid (200 μM) or kainic acid (400 μM) or NMDA (200 μM) was added to the culture wells (100 μM glutamic acid, 200 μM kainic acid and NMDA 100 μM final concentration). Cultures were incubated at 37° C. in the CO_2 incubator for 5 minutes for glutamic acid, 45 minutes for kainic acid and 10 minutes for NMDA exposure, after which time the media was replaced with 100 μl of 50% Neurobasal/2% N2 supplement (Invitrogen) and 50% balanced salt solution (BSS; see below). Cultures were incubated for a further 24 hours at 37° C. in the CO_2 incubator. The untreated controls with or without glutamic acid or kainic acid treatment received the same wash steps and media additions.

[0199] In one experiment, following the 15 minute CPP incubation (5 or 10 μM), the media in wells was removed and wells washed once in 300 μl of BSS before the addition of Neurobasal/2% 327 containing glutamic acid (100 μM/100 μl). Following this step, cultures were treated as described above. Untreated controls with or without glutamic acid exposure received the same wash steps and media additions. In addition, a post-glutamic acid exposure CPP treatment (5 μM) experiment was performed for the R9 peptide and the JNKI-1D-TAT control peptide. In this experiment, neurons were exposed to glutamic acid (100 μM) in 100 μl Neurobasal/2% 327 for 5 minutes as described above, after which time the media was removed and replaced with 50 μl Neurobasal/2% N2 supplement, followed by peptide (10 μM/50 μl in BSS) addition at 0 and 15 minutes post-glutamic acid exposure.

[0200] For pre-glutamic acid exposure experiments, neurons were exposed to peptide(s) for a 10 minute period, immediately before or 1, 2, 3, 4 or 5 hours prior to glutamic acid exposure. This was performed by removing media and adding 50 μl of Neurobasal/2% 827 containing peptide. After the 10 minutes at 37° C. in the CO_2 incubator, media was removed and replaced with 100 μl of Neurobasal/2% 327 (for immediate glutamic acid exposure media contained glutamic acid; 100 μM). At the relevant peptide pre-treatment time, media was removed and replaced with 100 μl of Neurobasal/2%. 327 containing glutamic acid (100 μM). Following 5-minute glutamic acid exposure, neuronal culture wells were treated as described above. For all experiments untreated controls with or without glutamic acid treatment underwent the same incubation steps and media additions.

Heparin Experiments

[0201] Heparin (for injection) was obtained from Pfizer (1000 IU/ml). Two different heparin experiments were performed: 1. Peptides were incubated with heparin (20 IU/ml) in Neurobasal/B27 for 5 minutes at room temperature, before addition to culture wells (50 μl) for 15 minutes at 37° C. in the CO_2 incubator. Following the incubation period, media in wells was removed and replaced with 100 μl of Neurobasal/2% B27 containing glutamic acid (100 μM), and subsequently treated as described above; 2. Media in wells was replaced with Neurobasal/2% B27 containing heparin (50 μl; 40 IU/ml) and incubated for 5 minutes at 37° C. in the CO_2 incubator. After the incubation period, peptides or glutamate receptor blockers (MK801/CNQX) in Neurobasal/2% B27 (50 μl) were added to the culture wells and cultures incubated for a further 10 minutes at 37° C. in the CO_2 incubator. Following the incubation period, media in wells was removed and replaced with 100 μl of Neurobasal/2% B27 containing glutamic acid (100 μM), and subsequently treated as described above. For all experiments, non-heparin treated peptide controls with glutamic acid treatment underwent the same incubation steps and media additions.

In Vitro Ischemia/OGD Model and Peptide Incubation

[0202] The in vitro ischemia model used for primary cortical neuronal cultures was performed as previously described (Meloni et at 2011) Briefly, culture media was removed from wells (glass 96-well plate format) and washed with 315 μl of glucose free balanced salt solution (BSS; mM: 116 NaCl, 5.4 KCl, 1.8 $CaCl_2$, 0.8 $MgSO_4$, 1 NaH_2PO_4; pH 6.9) before the addition of 60 μl BSS containing cell penetrating or control peptides (see Table 1). A non-peptide positive control consisting of the glutamate receptor blockers (5 μM MK801/5

μM 6-cyano-7-nitroquinoxaline: MK801/CNQX) was also included. In vitro ischemia was initiated by placing wells in an anaerobic incubator (Don Whitely Scientific, England; atmosphere of 5% CO_2, 10% H_2 and 85% argon, 98% humidity) at 37° C. for 55 minutes. Upon removal from the anaerobic incubator, 60 μl of Neurobasal/2% N2 supplement was added to the wells and cultures incubated for a further 24 hours at 37° C. in the CO_2 incubator. Control cultures received the same BSS wash procedures and media additions as ischemic treated cultures before incubation at 37° C. in the CO_2 incubator.

[0203] For pre-OGD exposure experiments the procedure was the same as described in the glutamic acid model, except the 10 minute peptide pre-treatment was performed using 100 μl Neurobasal/2% B27. Control cultures underwent the same BSS wash procedures and media additions as OGD treated cultures.

[0204] The in vitro ischemia model was also used for bEND3 cells, SH-SY5Y cells, and astrocytes. For bEND3 cells anaerobic incubation was extended to 2-3 hours and upon removal from the anaerobic incubator, 60 μl of DMEM/2% FCS was added to wells. For SH-SY5Y cells the first BSS wash step (315 μl) was omitted and anaerobic incubation was extended to 2-5 hours. Upon removal from the anaerobic incubator, 60 μl of DMEM/2% FCS was added to wells. For astrocytes, anaerobic incubation was extended to 1:15 to 2:00 hours and upon removal from the anaerobic incubator, 60 μl of DMEM/2% FCS was added to wells.

In Vitro Neuronal, bEND3 and Astrocyte Toxicity Model and Peptide Incubation

[0205] For neuronal cultures peptides were added to culture wells (96-well plate format) by removing media and adding 100 μl of 50% Neurobasal/2% N2 supplement and 50% BSS containing CPPs, JNKI-1 D-TAT or TAT-NR2B9c. Control cultures received of 50% Neurobasal/2% N2 supplement and 50% BSS media only. Cultures were incubation at 37° C. in the CO_2 incubator for 20 hours, after which time cell viability was assessed using the MTS assay. For bEND3 cultures, peptides were added to culture wells (96-well plate format) by removing media and adding 100 μl of DMEM/2% FCS containing peptide. Control cultures received 100 μl of DMEM/2% FCS only, Cultures were incubation at 37° C. in the CO_2 incubator for 0.5, 1 or 2 hours, after which time cell viability was assessed using the MTS assay. For astrocyte cultures peptides were added to culture wells (96-well plate format) by removing media and adding 100 μl of DMEM/2% FCS containing peptide. Control cultures received 100 μl of DMEM/2% FCS only. Cultures were incubation at 37° C. in the CO_2 incubator for 24 hours, after which time cell viability was assessed using the MTS assay.

Cell Viability Assessment and Statistical Analysis

[0206] Twenty-four hours after insult, neuronal cultures were examined by light microscopy for qualitative assessment of neuronal cell viability. Neuronal viability was quantitatively measured by 3-(4,5,dimethyliazol-2-yl)-5-(3-carboxymethoxy-phenyl)-2-(4-sulfophenyl)-2H-tetrazolium salt (MTS) assay (Promega, Australia). The MTS assay measures the cellular conversion of the tetrazolium salt to a water-soluble brown formazan salt, which is detected spectrophotometrically at 490 nm. MTS absorbance data were converted to reflect proportional cell viability relative to both the untreated and treated controls, with the untreated control taken as 100% viability, and presented as mean±SEM. For studies using astrocytes, bEND3, and SH-Y5Y cells, raw MTS data was used to generate graphs. Viability data was analysed by ANOVA, followed by post-hoc Fischer's PLSD test, with $P<0.05$ values considered statistically significant. Four- to six wells were used in all assays.

Rat Permanent Focal Cerebral Ischemia Model—Experimental Groups and Treatments

[0207] All treatments were randomized and administered in a blinded manner.

[0208] Administration of peptide (DR9: rrrrrrrrr-NH2; R12, R15, R18, protamine sulphate; protamine) or vehicle (saline: 0.9% NaCl) treatment solution was performed at 30 min post-MCAO. The peptide treatment comprised DR9 in saline (600 μl) to provide an intravenous loading dose of 1 μmol/kg or 1000 nmol/kg given over 5-6 min via the right jugular vein.

Rat Permanent Focal Cerebral Ischemia Model

[0209] This study was approved by the Animal Ethics Committee of the University of Western Australia. Male Sprague Dawley rats weighing 270 g to 350 g were kept under controlled housing conditions with 12 hour light-dark cycle with free access to food and water. Experimental animals were fasted overnight and subjected to permanent middle cerebral artery occlusion (MCAO) as follows.

[0210] Anaesthesia was induced with 4% isoflurane and a 2:1 mix of N_2O and O_2 via mask. Anaesthesia was maintained at 1.7-2% isoflurane. Cerebral blood flow (CBF) was monitored continuously using laser Doppler flowmetry (Blood FlowMeter, AD Instruments, Sydney, Australia). The probe was located 1 mm caudal and 4 mm lateral (right) to the bregma. A cannula was inserted in the right femoral artery to continuously monitor blood pressure and to provide samples for blood glucose and blood gas readings. Blood glucose was measured using a glucometer (MediSense Products, Abbott Laboratories, Bedford, Mass., USA) and blood gases were measured using a blood gas analyser (ABL5, Radiometer, Copenhagen, Denmark). Blood pressure was maintained at 80-100 mmHg. During surgery, rectal temperature was maintained at 37±0.5° C. and warming applied with a fan heater when necessary. For intravenous infusions, a length of PVC line primed with heparinised saline was tied in place in the right jugular vein, then externalised through a dorsal mid-scapular incision to a tether/swivel system (Instech Laboratories, Philadelphia, USA) designed to permit free movement.

[0211] The right common carotid artery (CCA) was exposed via a ventral neck incision. The external carotid artery (ECA) was isolated after cauterisation of the superior thyroid and occipital arteries. The isolated section of the ECA was ligated and cauterised to create a stump. The carotid body was removed and the pterygopalatine artery was ligated. A 4-0 nylon monofilament with a 0.39 mm diameter silicone tip (Doccol, Redlands, Calif., USA) was inserted through the ECA stump into the CCA and advanced rostrally into the internal carotid artery (ICA) until the laser Doppler flowmetry recorded a >30% decrease from baseline of cerebral blood flow. The monofilament was secured in two places (at the base of the ECA stump and on the ICA) for the remainder of the experiment. Animals were given post-operative anal-

gesia consisting of pethidine (3 mg/kg intramuscular) and bupivacaine (1.5 mg/kg subcutaneously) at head and leg incision sites.

[0212] Post-surgery animals were allowed to recover in a climate-controlled chamber and their core body temperature monitored and maintained at 37±0.5° C. by a cooling/heating fan when required for 3-4 hours.

Tissue Processing and Infarct Volume Measurement

[0213] Animals were sacrificed 24 hours post-MCAO with intra-peritoneal injections of sodium pentobarbitone (900 mg/kg). After euthanasia, the brain was removed and placed in a sterile container of 0.9% NaCl and then placed in a −80° C. freezer for 7 minutes. The brain was then coronally sliced from the junction of the cerebellum and cerebrum to 12 mm rostral to this point in 2 mm thick slices. Slices were immediately stained with 1% 2,3,5 triphenyitetrazolium chloride (TTC, Sigma, St Louis, Mo., USA) at 37° C. for 20 minutes, followed by fixation in 4% formalin at room temperature for at least 18-24 hours before infarct volume measurement. Slices were scanned and images were analysed by an operator blind to treatment status using ImageJ 3rd edition (NIH, USA). The total infarct volume was determined by adding the areas of infarcted tissue on both sides of the 2 mm sections. These measured areas were multiplied by half slice thickness (1 mm), and corrected for cerebral oedema by multiplying the ratio of affected to normal hemisphere areas.

Statistical Analysis

[0214] For infarct volume measurements, the peptide treatment group was compared to the vehicle control group by student Mest (R9D trial) or ANOVA, followed by post-hoc Fischer's PLSD test (R12, R15, R18 and Ptm trial).

Experimental Example 1

Neuroprotection Following Glutamic Acid Exposure

[0215] The CPPs TAT-D, R9, and penetratin provided significant neuroprotection in a dose response manner (FIG. **1***a*, Table 3). Visual assessment of cultures post-injury also confirmed the neuroprotective effect that ranged from 5% for untreated glutamic acid exposed cultures to 100% survival for R9 treated cultures. R9 was the most potent peptide with an IC50 value of 0.78 μM, followed by penetratin (IC50: 3.4 μM) and TAT-D (IC50: 13.9 μM). The Pep-1 peptide was ineffective. The glutamate receptors blockers and control peptides (JNKI-1D-TAT, PYC36L-TAT) were also highly effective in this model (FIG. **1***a*).

[0216] In addition, the TAT-D peptide displayed a similar level of neuroprotection as the TAT-L peptide (FIG. **1***b*). When CPPs were washed-out prior to glutamic acid exposure only R9 (in this experiment) displayed high level neuroprotection (FIG. **1***c*),

[0217] The R9 and R12 peptides were also highly effective when added immediately after glutamic acid exposure, and R9 mildly effective when added at 15 minutes post-insult. In contrast, the JNKI-1 D-TAT and NR29c (also referred to as TAT-NR2B9c) peptides did not significantly increase neuronal survival when added immediately after, or at 15 minutes post-glutamate exposure (FIG. **1***d*).

[0218] FIGS. **1***e-j* provide additional efficacy data in the glutamate model for peptides R1, R3, R6, R9, R12, R15, R18, R9/E9 (also referred to as E9/R9), R9/tPA/R9 (also referred to as R9/X7/R9) as well as control peptides JNKI-1 D-TAT and NR29c.

[0219] In dose response studies using R1, R3, R6, R7, R8, R9, R12, R15 and R18 in the glutamate model revealed that: i) R1, R3, R6 and R7 displayed no to little neuroprotection; ii) R8 displayed neuroprotection at 5 μM, (iii) the order of potency for the other peptides was R15>R18>R12>R9; and iv) neuroprotective efficacy for R15 and R18 was reduced at the higher concentration (5 μM); see Table 4, FIGS. **1***e*, **1***l*, **1***j*, **6**, **7**, and **8**.

[0220] In a dose response study using R9, DAHK (last four end N-terminal amino acids of protein albumin) PTD4 (modified TAT peptide with 33× increased cell penetrating ability; (Ho et al, 2001). R9/E9 (Arg-9/Glu-9; neutral peptide) and R9/tPA/R9 (tissue plasminogen activator enzyme peptide cleavage site flanked by R9) in the glutamate model revealed that: i) PTD4 and R9/E9 displayed no to little neuroprotection; DAHK had low level neuroprotection; and ii) R9/tPA/R9 had a potency between R12 and R18. Also the TAT-NR29C peptide (C-terminal NR2B NMDRA receptor subunit peptide; blocks NMDAR signaling with PSD-95 protein to block NO (nitrous oxide) production; Arts et al 2002) was ineffective. See Table 4 and FIGS. **1***d, g, h.*

[0221] Peptide R12 was more effective than R9 (based on neuroprotection at 0.625 μM concentration) and both were more effective compared to PCY-36-TAT, in the glutamic acid model, while NR29c was ineffective (FIG. **1***g*). Peptide R12 was more effective than R9 (based on neuroprotection at 0.5 μM and 1 μM concentrations, while FR1, R3, R6 and NR29c were ineffective (FIG. **1***i*). Peptide R9 synthesized by two different companies also had similar efficacy in the glutamate model (FIG. **1***j*).

[0222] Peptides R9, R12, R15 and R18 were effective when added to neuronal cultures during the 5 minute glutamic acid insult only (FIG. **28**), or removed from cultures prior to the insult following a 10 minute pre-exposure (FIG. **29**).

[0223] Peptides R12 and R15 were effective when added to neuronal cultures for 10 minutes, 1 to 4 hours prior to the glutamic acid insult (FIG. **30**).

[0224] Peptides PTD4 shows low level neuroprotection, and peptide E91R9 shows no protection in the glutamic acid model (FIG. **33**), while arginine-rich peptides XIP and NCXBP3 show high levels of protection (FIG. **34**, **35**). Poly-lysine-10 peptide (K10) and TAT-NR2B9c peptides show low level neuroprotection in glutamic acid (FIG. **36**) and NMDA models (FIG. **37**), respectively. R8 and R9 fused to calpain cleavage site (Cal/R9) show moderate to high level neuroprotection in glutamic acid (FIG. **38**). FIGS. **39** and **40** show that the negatively charged molecule heparin blocks neuroprotective actions of R9D, R12, R15, and PYC36-TAT, but not glutamate receptors blockers (5 μM K801/5 μM CNQX) in the glutamic acid model. FIG. **41** shows that the JNKI-1 peptide when fused to the (non-arginine) kFGF CPP, which does not rely on endocytosis for uptake, was not neuroprotective in the glutamic acid model; the kFGF peptide was also ineffective. In contrast, TAT-JNKI-1 and JNKI-1-TATD were neuroprotective. FIG. **44** shows that peptides R9D, R12, R15, and PYC36-TAT, TAT, TAT-NR2B9c, TAT-JNKI-1 and JNKI-1-TATD and glutamate receptors blockers (5 μM K801/5 μM CNQX) to varying degrees reduced calcium influx in neuronal cultures after treatment with glutamic acid.

Experimental Example 2

Neuroprotection Following Kainic Acid Exposure

[0225] Following kainic acid exposure TAT-D, R9 and penetratin were neuroprotective, but less effective than in the glutamic acid model, and did not always display a typical dose response pattern (FIG. **2**, Table 2). Pep-1 was ineffective. R9 was the most potent peptide, increasing neuronal survival from ≈20% to a maximum of ≈80%. The respective IC50 values for R9, penetratin, and TAT-D were 0.81, 2.0 and 6.2 μM. The glutamate receptors blockers, JNKI-1D-TAT and PYC36L-TAT were also effective in this model (FIG. **2**).

Experimental Example 3

Neuroprotection Following In Vitro Ischemia/Oxygen Glucose Deprivation (OGD)

[0226] Following in vitro ischemia all four CPPs displayed neuroprotective effects (FIG. **3**, Table 2). Neuroprotection with Arg-9 (IC50: 6.0 μM) and TAT-D (IC50: 7.1 μM) was similar; efficacy followed a dose response pattern and increased neuronal survival from 10% to 40-50%. Neuroprotective efficacy was lost with increasing concentrations of penetratin (≤5 μM), while Pep-1 was only neuroprotective at lower concentrations (1-5 μM). Glutamate receptors blockers and PYC36L-TAT were also effective in this model (FIG. **3***a*).

[0227] In addition, when added post-in vitro ischemia R9, R12, R15 and R18 displayed neuroprotective effects, however higher concentrations of R15 and R18 reduced efficacy (FIG. **3***b*).

[0228] R9 also reduced bEND3 and SH-5YSY cell death when exposed to in vitro ischemia (FIG. **3***c*). R18 also reduced astrocyte cell death when exposed to in vitro ischemia (FIG. **42**).

[0229] FIG. **6** shows a dose response study using R9, R10, R11, R12, R13 and R14 in the glutamate model, which revealed that all peptides displayed significant neuroprotection between 1 and 5 μM, except for R11 which displayed significant neuroprotection at 2 and 5 μM. Mean±SEM: N=4; *P<0.05. (Peptide concentration in μM).

[0230] FIG. **7** shows a dose response study using R9E), R13, R14 and R15 in the glutamate model, which revealed that all peptides displayed neuroprotection between 1 and 5 μM. Mean±SEM: N=4; *P<0.05. (Peptide concentration in μM).

[0231] As shown in FIG. **8**, in a dose response study using R6, R7, R8, and R9 in the glutamate model, it was revealed that peptides R8 and R9 displayed significant neuroprotection at 5 μM and 1 μM and 5 μM concentrations, respectively, while R6 and R7 did not exhibit significant neuroprotection. Mean±SEM: N=4; *P<0.05. (Peptide concentration in μM). FIG. **31** shows a dose response study using R9, R12, R15 and R18 when peptides were added for 15 minutes after OGD. Neuroprotection is displayed for R12, R15 and R18, but not R9 at 1 μM and 5 μM.

[0232] Peptides R12 and R18 were effective when added to neuronal cultures for 10 minutes, 1 to 3 hours prior to OGD (FIG. **32**),

TABLE 3

IC50 values of cell penetrating and control peptides for the three injury models

Peptide	SEQ ID NO.	IC50: Glutamic acid model (μM)	IC50: Kainic acid model (μM)	IC50: In vitro ischemia model (μM)
Arg-9 (R9)	6	0.78	0.81	6.0
TAT-D	20	13.9	6.2	7.1
Penetratin	22	3.4	2.0	N/A
Pep-1	23	N/A	N/A	>15
PYC36L-TAT#	24	1.5	—	—
JNKI-1D-TAT#	25	2.1	6.5	—

* Based on dose response graphs shown in FIG. 1a, FIG. 2 and FIG. 3a.

#IC50 values for JNKI-1D-TAT and PYC36L-TAT peptides from Meade et al. (2010a,b).

N/A = not applicable because peptides were either ineffective or increased cell death at higher doses.

— = data not available.

TABLE 4

IC50 values of polyarginine peptides for glutamic acid models*

Peptide	SEQ ID NO.	IC50: Glutamic acid model (μM)	95% confidence intervals (μM)
Arg-1 (R1)	1	>5 μM	N/A
Arg-5 (R3)	2	>5 μM	N/A
Arg-6 (R6)	3	>5 μM	N/A
Arg-9 (R9)	6	0.83	0.16-4.1
Arg-12 (R12)	9	0.44	0.16-1.2
Arg-15 (R15)	12	0.19	0.06-0.6
Arg-18 (R18)	13	0.24	0.08-0.75
R9/tPA/R9	16	0.29	0.06-1.4

*Based on dose response graph shown in FIG. 1e.

N/A = not applicable because peptides had no or little effect at highest concentration tested (5 μM).

Experimental Example 4

Animal Trial

[0233] In an initial animal trial that was conducted, it was shown that Arg-9 (R9), R18 and protamine (Ptm) possessed neuroprotective activity in vivo. These trials showed the efficacy of R9D peptide in rat permanent middle cerebral artery occlusion (MCAO) stroke model. R9D peptide was administered intravenously 30 min post-MCAO. Infarct volume (brain injury) was measured 24 h post-MCAO (mean±SEM). This is shown in FIGS. **5** and **27** where it can be seen that (Ns=812 animals for each group) treatment with R9D, R18 and protamine (Ptm) showed a statistically significant neuroprotective effect by reducing infarct volume (brain damage) by approximately 20% after a MCAO stroke.

General Observations and Discussion

[0234] The Applicant assessed TAT as known neuroprotective example and three other CPPs (penetratin, R9, and Pep-1) for their neuroprotective properties in cortical neuronal cultures following exposure to glutamic acid, kainic acid, or in vitro ischemia (oxygen-glucose deprivation).

[0235] In addition, polyarginine peptides (R9, R12, R15, R18) and/or arginine-rich protamine peptide were also assessed in astrocyte, brain endothelial cell line (bEND3), and/or a neuroblastoma cell line (SH-SY5Y) cultures using the in vitro ischemia model.

[0236] R9, penetratin and TAT-D displayed consistent and high level neuroprotective activity in both the glutamic acid (IC50: 0.78, 3.4, 13.9 μM) and kainic acid (IC50: 0.81, 2.0, 6.2 μM) injury models, while Pep-1 was ineffective.

[0237] The TAT-D isoform displayed similar efficacy to the TAT-L isoform in the glutamic acid model. R9 displayed efficacy when washed-out prior to glutamic acid exposure. However, R9 was significantly more effective than peptides that had previously been shown to be neuroprotective, i.e. TAT-D, TAT-L, PYC36L-TAT, and JNKI-1D-TAT.

[0238] Neuroprotection following in vitro ischemia was more variable, with all peptides providing some level of neuroprotection (IC50; R9: 6.0 μM, TAT-D: 7.1 μM, penetratin/Pep-1: >10 01). The positive control peptides JNKI-1D-TAT (JNK inhibitory peptide) and/or PYC36L-TAT (AP-1 inhibitory peptide) were neuroprotective in all models.

[0239] In a post-glutamic acid treatment experiment, R9 was highly effective when added immediately after, and mildly effective when added 15 minutes post-insult, while the JNKI-1D-TAT control peptide was ineffective when added post-insult.

[0240] In an initial animal trial that was conducted, it was shown that R9, R12, R18, and protamine possessed neuroprotective activity in vivo.

[0241] In a dose response study using R1, R3, R6, R9, R12, R15 and R18 in the glutamate model revealed that: i) R1, R3, R6, and R7 displayed no to little neuroprotection; ii) the order of potency for the other peptides was R15>R18>R12>R9; and iii) neuroprotective efficacy for R15 and R18 was reduced at the higher concentration tested (5 μM).

[0242] In a dose response study using R9, DAHK (last four end N-terminal amino acids of protein albumin), PTD4 (modified TAT peptide with X33 increased cell penetrating ability; Ho et al, 2001), R9E9 (R9/Glu-9; neutral peptide) and R9/tFA/R9 (tissue plasminogen activator enzyme peptide cleavage site flanked by R9) in the glutamate model revealed that: I) PTD4 and R9/E9 displayed no to little neuroprotection; DAHK had low level neuroprotection; and ii) R9/tPA/R9 had a potency between R12 and R18. Also the TAT-NR2B9C peptide (C-terminal NR2B NMDRA receptor subunit peptide blocks NMDAR signaling with PSD-95 protein to block NO production; Aarts et al., 2002). Polyarginine and arginine-rich (protamine) peptides could also reduce astrocyte, bEND3, and SH-SY5Y cell death following in vitro ischemia.

[0243] These findings demonstrate that the peptides of the invention have the ability to inhibit neurodamaging events/pathways associated with excitotoxic and ischemic injuries. Poly-arginine peptides with 9 arginine amino acid residues are particularly neuroprotective.

[0244] The cytoprotective properties of the peptides of the invention suggests they are ideal carrier molecules to deliver neuroprotective drugs to the CNS following injury and/or to serve as potential neuroprotectants in their own right.

[0245] The peptides of the invention thus exhibit neuroprotective properties in different in vitro injury models that have been shown to be translatable into in vivo models. This is further bolstered by the neuroprotective effect shown in the initial animal trials that were conducted. The superior neuroprotective action of R9 was surprising; based on IC50 values R9 was 17 and 7 fold more potent than TAT-D in glutamic acid and kainic acid models respectively, and was the only peptide effective even when washed-out prior to glutamate acid exposure. This finding suggests the increased arginine residues and/or the slightly higher net charge (10 vs 9 at pH 7) of R9 are important factors for neuroprotection following excitotoxicity. Furthermore, while the exact reason for the loss of efficacy of TAT and penetratin, but not R9 following wash-out prior to glutamic acid exposure is unclear, it may relate to the speed of R9 intracellular up-take, rather than an extracellular mechanism. This is supported by the finding that R9 was effective when added after glutamic acid exposure, while the JNKI-1D-TAT peptide was ineffective.

[0246] Furthermore, when arginine and polyarginine peptide(s) R1, R3, R6, R9, R12, R15 and R18 were assessed in the glutamic acid injury model only peptides R9, R12, R15 and R18 showed significant neuroprotection at the doses tested; R15 appeared to be the most potent peptide. A hybrid R9 peptide (R9/tPA/139) containing the tPA cleavage linker site was also highly effective in the glutamic acid model. R9 was also more effective than R12 when added post-glutamic acid exposure. Interestingly, PTA4 (modified TAT peptide with 33× improved transduction efficacy when compared to regular TAT; Ho et al, 2001), the R9/E9 hybrid and the NR29c (a TAT fused peptide that blocks NMDA/glutamate receptor-induced NO production) and DAHK (last four end N-terminal amino acids of protein albumin) were largely ineffective following glutamic acid exposure.

[0247] Peptides R9, R12, R15 and R18 were also effective in the in vitro ischemia model when added after anaerobic incubation (i.e. during reperfusion phase of injury). R9 was also able to protect brain endothelial cells (bEND3 cells) and neuroblastoma cells (SH-5YSY cells) following in vitro ischemia.

[0248] As mentioned hereinbefore, a result in the study was the demonstration that penetratin and Pep-1 also exhibited neuroprotective properties. The penetratin and Pep-1 peptides bear no amino-acid sequence relatedness to each other, or the TAT/R9 peptides. Interestingly penetratin was highly neuroprotective in the excitotoxic models (IC50s: 3.4 and 2 μM), but less effective in the in vitro ischemia model, with increasing concentrations reducing efficacy. The Pep-1 peptide was generally ineffective in the excitotoxic models and in some experiments appeared to increase neuronal death (data not shown), but was neuroprotective following in vitro ischemia at lower concentrations. Interestingly, when penetratin was washed-out from neuronal cultures prior to glutamic acid exposure, visual observations revealed that the peptide did display some early neuroprotective effects (data not shown). Hence, both penetratin and Pep-1 behaved differently to each other and the TAT/R9 peptides in the injury models.

[0249] The differential neuroprotective responses for the four CPPs in the excitotoxic and ischemic injury models is likely to be related to the peptides' physical-chemical properties, and more specifically their endocytic-inducing properties. Furthermore, it is likely that the neuroprotective action of the CPPs is mediated at the cell membrane (e.g. receptors, ion channels), Xu et al (2008), have suggested that TAT may alter the cell membrane and thereby affect the function of cell surface receptors, such as the NMDA receptor, resulting in reduced calcium influx.

[0250] It is contemplated, however, that the peptide or peptides of the invention can act to block NMDA receptor functioning and/or block, downregulate, or decelerate the influx of calcium. An alternative mechanism is that the CPPs interact and stabilise the outer mitochondrial membrane and thereby help to preserve mitochondrial function. Potential benefits are maintenance of ATP synthesis, reduced reactive oxygen spe-

cies production, and improved calcium handling. To this end, the Applicant has observed that Arg-9 can increase MTS absorbance levels above baseline levels in normal neurons and following injury (e.g. FIG. **1**A, 15 μM). Since reduction of MTS to its formazan product primarily occurs in mitochondria, the ability of Arg-9 to increase formazan levels is supportive that the peptide is improving mitochondrial function. Another potential mechanism especially in relation to R9 and TAT, is that these arginine rich peptides are inhibiting the calcium-dependent pro-protein convertase enzyme furin (Kacprzak et al. 2004), and thereby blocking activation of potentially damaging proteins.

[0251] The invention demonstrates that cationic amino acid rich CPP, particularly arginine-rich CPPs or carrier-peptides (e.g. R12, R15, protamine), display a high level of neuroprotection, as opposed to CPPs in general. This raises the possibility that the mechanism of action of a neuroprotective peptide fused to a CPP is largely, if not exclusively the result of an enhanced neuroprotective effect of the carrier-peptide. Furthermore, the mechanism by which arginine-rich CPPs exert their neuroprotective action may be linked to endocytosis, a predominant carrier-peptide cellular uptake route, rather than by an interaction with a specific cytoplasmic target. In contrast, a neuroprotective peptide fused to a carrier-peptide entering a cell by endocytosis must first escape the endosome, which is known to be a highly inefficient process (Al-Taei et al., 2006; El-Sayed et ale 2009; Appelbaum et al., 2012; Qian et al., 2014), before it can interact with its cytoplasmic target, hereby rendering it highly unlikely that the peptide can act through interaction with its intended target.

[0252] With respect to CPP intracellular entry, the predominant mechanism is considered to be by endocytosis (macropinocytosis) (Palm-Apergi et al. 2012). Although less relevant to the present invention, a recent report has demonstrated that cargo properties may also promote a direct cell entry mechanism by certain CPPs (Hirose et al. 2012). However, what is potentially highly relevant is how specific cargos, peptide or otherwise, may affect CPPs by enhancing their neuroprotective action, improving translocation efficiency and/or as demonstrated by Cardozo et al (2007) increasing their toxicity. This is especially important when the cargo itself is neuroprotective, because as mentioned above, this makes discerning the neuroprotective effect between the CPP and the cargo very difficult. For example, in a previous studies (Meade et al. 2010a), the addition of three amino acid residues (Pro, Lys, Ile) from the PYC36 peptide to the TAT-D peptide (AM8D-TAT) resulted in 1050 values decreasing from >15 μM for TAT-D to 1.1 μM for AM8D-TAT in the glutamic acid model.

[0253] A positive effect with the TAT peptide control has not always been observed. There are a number of possible explanations and to address this question: it is first necessary to differentiate studies using the TAT peptide only (i.e. GRKKRRQRRRG), versus studies using TAT fused to a reporter protein (e.g. GFP, β-gal) or peptide (e.g. HA and/or 6×HIS tag, scrambled peptide) as a control. With respect to the studies that have used the TAT peptide by itself as a control, it is possible TAT was ineffective at the dose used and/or the injury model was too severe to uncover a neuroprotective effect. For example, Boresello at al. (2003) did not detect a neuroprotective effect with the TAT peptide following a 12, 24 or 48 hour exposure of cortical neuronal cultures to 100 μM NMDA. In contrast the L-JNKI-1 peptide was effective at 12 and 24 hours, while the protease resistant D-JNKI-1 peptide was effective et all time-points. Given the superior efficacy of the JNKI-1 peptides compared to the TAT peptide, it is possible that at the concentration tested, TAT was not neuroprotective or that any neuroprotective effects were overridden due to NMDA insult severity. In a study by Ashpole and Hudmon (2011) a modest protective effect with the TAT peptide was observed in cortical neuronal cultures following glutamic acid exposure. Furthermore, the authors concluded that since the TAT peptide provided little protection, the neuroprotection observed for their CAMKII inhibitory peptide was not due to the "import sequence" (i.e. TAT). However, it cannot be ruled out that the CAMKII inhibitory peptide increased the potency of the TAT peptide. Lastly, it is possible that the TAT peptide is only neuroprotective in specific injury models and cell types.

[0254] In studies using TAT fused to a reporter protein or control peptide, in addition to the points raised above, it is also likely that the control protein/peptide may act to dampen or nullify the TAT peptide's neuroprotective properties. Based on the many studies that have used TAT-fused proteins/peptides as controls and showed no neuroprotective effects, this would appear to be the case (e.g. Kilic et al. 2003; Doeppner et al. 2009). It needs to be borne in mind, however, that the mere fact that a protein is a CPP does not necessarily mean that it will be neuroprotective, which is borne out by the fact that PTD-4 peptide (a modified TAT peptide with 33× better transduction efficiency than TAT itself; Ho et al, 2001) has little to no neuroprotective properties.

TABLE 5

Amino acid sequences of different protamine (salmon) peptides; amino acid residues/arginine residues and molecular weights.

SEQ ID NO.:	Name of Sequence	Type	Other information	Sequence	aa's/arg residues	MW (da)
—	Protamine sulphate mixture; Ptm	Poly-peptide mixture	injectable/ IV form	Protamine 1 - Protamine 4[1]	32/21	≈4,500
32	Protamine 1; Ptm1	Poly-peptide	Peak 1 HPLC[a]	PRRRRRSSSRPIRRRRR PRASRRRRRGGRRRR	32/21	4,236
33	Protamine 2; Ptm2	Poly-peptide	Peak 2 HPLC[a]	PRRRRSSRRPVRRRRR PRVSRRRRRGGRRRR	31/21	4,163

TABLE 5-continued

Amino acid sequences of different protamine (salmon) peptides; amino acid residues/arginine residues and molecular weights.

SEQ ID NO.:	Name of Sequence	Type	Other information	Sequence	aa's/arg residues	MW (da)
34	Protamine 3; Ptm3	Poly-peptide	Peak 3 HPLC[a]	PRRRRSSSRPVRRRRR PRVSRRRRRGGRRRR	31/20	4,094
35	Prolamine 4; Ptm4	Poly-peptide	Peak 4 HPLC[a]	PRRRRASRRIRRRRRPR VSRRRRRGGRRRR	30/21	4,064
36	Protamine 5; Ptm5	Poly-peptide	SwissProt[c]	PRRRRSSSRPVRRRRR PRVSRRRRRGGRRRR	32/21	4,250
37	Low molecular weight protamine (LMWP)	Poly-peptide	Derived from protamine[b]	VSRRRRRGGRRRR	14/10	1,880
38	Protamine 5 nucleotide sequence	Ptm 5, DNA coding sequence	SwissProt[c]	5'ATGCCCAGAAGACGC AGATCCTCCAGCCGAC CTGTCCGCAGGCGCCG CCGCCCTAGGGTGTCC CGACGTCGTCGCAGGA GAGGAGGCCGCAGGA GGCGT-3'	N/A	N/A

(Protamine peptide sequences (salmon) present in protamine sulphate for clinical use or SwissProt data base. [a = Peaks 1 - 4 identified following HPLC of protamine sulphate[1]: b = Sequence in SwissProt (Swissprot: P14402). (1) Hoffmann J. A. 1, Chance R. E., Johnson M. G. 1990, Purification and analysis of the major components of chum salmon protamine contained in insulin formulations using high-performance liquid chromatography. Protein Expr Purif. 1(2): 127-33. (2) Chang L. C., Lee H. F., Yang Z., Yang V. C. 2001. Low molecular weight protamine (LMWP) as nontoxic heparin/low molecular weight heparin antidote (I): preparation and characterization PharmSci. 3(3): E17).

Experimental Example 1

Neuroprotection Following Glutamic Acid Exposure

[0255] Protamine sulphate (protamine; Ptm) provided significant neuroprotection in a dose response manner (FIGS. **9**, **10**, **12**, **13**, **15**). Visual assessment of cultures post-injury also confirmed the neuroprotective effect that ranged from for untreated glutamic acid exposed cultures to 85-100%% survival for protamine treated cultures. In addition, a 5 or 10 minute protamine pre-exposure was also highly neuroprotective resulting 100% neuronal survival (FIG. **11**). In dose response experiments, low molecular weight (LMWP), protamine 1 (Ptm1), protamine 2 (Ptm2), protamine 3 (Ptm3), protamine 4 (Ptm4), protamine 5 (Ptm5), peptide were also neuroprotective (FIGS. **12**, **13**, **15**).

[0256] In protamine and LMWP pre-exposure experiments, protamine was neuroprotective when neurons where exposed to protamine immediately before and 1 or 2 hours prior to glutamic acid insult, while LMWP was only neuroprotective when exposure was immediately before glutamic acid insult (FIG. **14**).

Experimental Example 2

Neuroprotection Following Oxygen-Glucose Deprivation (OGD)

[0257] In the OGD model protamine was neuroprotective when neurons were treated with peptide 1 hour before insult (FIG. **18**) or post-insult (FIG. **16**, **17**) In addition, when added for 15 or 30 minutes, post-OGD protamine was also neuroprotective (FIGS. **19**, **20**, **21**, **22**), LMWP was not neuroprotective when neurons were pre-exposed to the peptide 1 hour before OGD, but it was neuroprotective when added for 15 minutes post-OGD. In addition when protamine peptides (Ptm1-Ptm5) and LMWP were added for 15 minutes post-OGD, peptides Ptm2, Ptm4, Ptm5 and LMWP were neuroprotective (FIG. **22**).

Experimental Example 3

Protection of bEND3 cells Following Oxygen-glucose Deprivation (OGD)

[0258] In the OGD model, protamine and protamine 4 (ptm4) was protective for blood brain barrier (bEND3) endothelial cells when treated with peptide 15 minutes before OGD (FIG. **23**, **24**). In addition, exposure of bEND3 to protamine at concentrations ranging from 1.25 to 15 μM for between 0.5 to 2 hours did not cause any significant toxicity based on MTS assay (FIG. **25**, **26**). FIG. **43** shows that Ptm1 Ptm5, and low molecular weight protamine (LMWP) at concentration from 2.5 to 10 μM did not cause significant astrocyte cell death following 24 hour exposure.

General Observations and Discussion

[0259] The Applicant assessed the arginine-rich protamine sulphate (protamine; Ptm), protamine peptides 1-5 (Ptm1-Ptm5, SEQ. ID. NOs. 32 to 36, respectively), and low molecular weight protamine (LMWP, SEQ. ID. NO. 37) for their neuroprotective properties in cortical neuronal cultures following exposure to glutamic acid or in vitro ischemia (oxygen-glucose deprivation—OGD). Both injury models are commonly used to mimic the effects of ischemic stroke.

[0260] The Applicant also assessed the use of protamine peptides in protecting blood brain barrier (bEND3) endothelial cells from OGD.

[0261] Protamine displayed consistent and high-level neuroprotective activity in both the glutamic acid and OGD injury models, while protamine also provided protection in the bEND3 cells. LMWP was slightly less effective (based on dose concentrations to achieve equivalent neuroprotection as protamine) in the neuronal glutamic acid and OGD injury models. This is most likely due to the LMWP peptide containing fewer arginine residues. Protamine peptides 1-5 (Ptm 1-Ptm5) were also highly neuroprotective in the in the glutamic acid model, while Ptm2, Ptm4 and Ptm5 were neuroprotective in the OGD model.

[0262] In a OGD study using bEND3 cells, a 15-minute pre-exposure with protamine significantly increased cell viability and thus protection, after different duration of OGD (2 h:15 min, 2 h:30 min or 2 h:45 min). In addition, a 15-minute pre-exposure with Ptm4 also significantly increased cell viability and thus protection, in the OGD model.

[0263] In a bEND3 toxicity study using protamine at varying concentrations, it was revealed that protamine is not toxic even at concentrations as high as 15 μM.

[0264] These findings demonstrate that protamine peptides of the invention have the ability to inhibit neurodamaging events/pathways associated with excitotoxic and ischemic injuries. Also, due to the effects of protamine in the pre-exposure trials, one new key finding was that protamine treatment of neurons 1 to 2 hours before glutamic acid or OGD exposure can induce a neuroprotective response, by reducing cell death. This is significant because there are a number of cerebrovascular (e.g. carotid endarterectomy) and cardiovascular (e.g. coronary artery bypass graft) surgical procedures where there is a risk a patient can suffer cerebral ischemia or a stroke resulting in brain injury. Therefore, protamine peptides may be able to be given 1-2 hours before such a procedure to protect the brain against any such cerebral ischaemic event.

[0265] The cytoprotective properties of the peptides of the invention suggest they are ideal neuroprotective drugs for the treatment of CNS injuries. In addition, as they are also likely to have cell penetrating properties [protamine is FDA approved for gene therapy delivery (DNA, viral vectors; Sorgi et al, 1997) and LMWP is used as a cell penetrating peptide; Park et al, 2005] they are ideal carrier molecules to deliver neuroprotective drugs to the CNS following injury.

[0266] The neuroprotective effects of the peptides of the invention are likely to be related to the peptides' physical-chemical properties. Furthermore, it may well be that the neuroprotective action of arginine-rich protamine peptides is mediated at the cell membrane (e.g. receptors, ion channels). Studies have suggested that arginine-rich peptides including TAT (Xu et al, 2008), R6 (Ferrer-Montiel et al 1988) and R9-CBD3 (Feldman and Khanna 2013) and TAT-CBD3 (Brustovetsky et al 2014) may affect the function of cell surface receptors and ion channels, such as the NMDA receptor, resulting in reduced calcium influx. It is contemplated, however, that the peptide or peptides of the invention can act to block NMDA receptor functioning and/or block, down-regulate, or decelerate the influx of calcium. An alternative mechanism is that the protamine peptides interact and stabilise the outer mitochondrial membrane and thereby help to preserve mitochondrial function. Potential benefits are maintenance of ATP synthesis, reduced reactive oxygen species production, and improved calcium handling. To this end, the Applicant has observed that protamine can increase MTS absorbance levels above baseline levels in normal neurons and following injury (e.g. FIG. **11**, **12**; 5 μM). Since reduction of MTS to its formazan product primarily occurs in mitochondria, the ability of protamine to increase formazan levels is supportive that the peptide is improving mitochondrial function. Another potential mechanism is that these arginine-rich peptides are inhibiting the calcium-dependent pro-protein convertase enzyme furin (Kacprzak et al. 2004), and thereby blocking activation of potentially damaging proteins.

[0267] With respect to protamine peptide intracellular entry, the predominant mechanism for arginine-rich peptides is considered to be by endocytosis (macropinocytosis) (Palm-Apergi et al. 2012). It is therefore likely, that during peptide endocytosis across the plasma membrane, it results in endosomal internalisation of cell surface structures (see FIG. **46**). In the setting of neuronal excitotoxicity and ischemia, the down-regulation of ion channels would be beneficial as it reduces the normally neuro-damaging influx of calcium and other ions.

[0268] The Applicant is of the opinion that they have identified a new class or group of peptides that can serve as CPPs as well as neuroprotective peptides. The Applicant has found that poly-arginine or arginine-rich peptides, particularly those selected from protamine or Low Molecular Weight Protamine (and mixtures and derivatives thereof, especially in the form of commercially available protamine sulphate) posses novel neuroprotective or neuro-active properties. There is evidence that the peptides disclosed herein as part of the invention possess the same range of neuroprotective or neuro-active properties when used in vivo (Vaslin et al. 2009) and find use in treating neural injuries.

[0269] The Applicant has thus found that arginine-rich peptides and CPPs unrelated to TAT posses novel neuroprotective properties, in particular poly-arginine sequences and sequences of between 10 and 32 amino acids in length which possess more than 10 arginine residues (such as protamine, LMWP, and derivatives thereof). There is evidence that CPPs of the invention possess the same range of neuroprotective properties when used in vivo (Vaslin et al. 2009) and find use in treating neural injuries.

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1-30. (canceled)

31. An isolated peptide for the treatment or prevention of neural injury, said isolated peptide comprising 10 to 32 amino acid residues in length, wherein the isolated peptide includes at least 10 to 22 arginine residues.

32. The peptide as claimed in claim **31**, wherein the isolated peptide has an arginine content of at least 30%.

33. The peptide as claimed in claim **32**, wherein the isolated peptide has an arginine residue content of at least 90%.

34. The peptide as claimed in claim **31**, wherein the isolated peptide is a poly-arginine peptide comprising 10 to 18 arginine residues.

35. The peptide as claimed in claim **31**, wherein the isolated peptide comprises any one or more of the peptides selected from the group consisting of SEQ. ID. NOS. 7, 8, 9, 10, 11, 12, 13, 16, 22, 30, 31, 32, 33, 34, 35, 36, 37, and functional fragments and analogues thereof having neuroprotective activity.

36. The peptide as claimed in claim **31**, wherein the isolated peptide includes at least one poly-arginine segment comprising at least 4 contiguous arginine residues.

37. The peptide as claimed in claim **31**, wherein the isolated peptide comprises a mix of protamine derivatives.

38. The peptide as claimed in claim **37**, wherein the mix of protamine derivatives comprises protamine sulphate.

39. The peptide as claimed in claim **31**, wherein the isolated peptide treats or prevents neural injury by one or more mechanisms selected from the group consisting of promoting the survival of neurons, inhibiting neuronal cell death, affecting the endocytic processes of the cell; affecting the function of cell surface receptors to result in reduced cellular calcium influx; interacting with and/or stabilises the outer mitochondrial membrane to preserve mitochondrial function; and inhibiting, downregulating, or affecting the calcium-dependent pro-protein convertase enzyme furin.

40. The peptide of claim **32**, wherein the isolated peptide is included within, or fused to, one or more polypeptides.

41. The peptide of claim **40**, wherein the isolated peptide is fused to a second peptide with at least one linker sequence.

42. The peptide of claim **32**, wherein the isolated peptide exhibits neuroprotective activity at IC50 levels of less than 10 μM.

43. An isolated polynucleotide sequence encoding a peptide for the treatment or prevention of neural injury, said polynucleotide sequence comprising:

a codon sequence coding for a 10 to 32 amino acid peptide having at least 10 to 22 arginine residues,

a complementary sequence that is complementary to the codon sequence,

a hybridization sequence that hybridizes under stringent conditions with the codon sequence, and

a homology sequence having at least 60% homology with the codon sequence,

wherein the isolated polynucleotide sequence is a non-naturally occurring polynucleotide, a man-made artificial construct, cDNA, or a vector including the isolated nucleic acids.

44. The isolated polynucleotide sequence as claimed in claim **43**, wherein the isolated polynucleotide sequence is incorporated into a pharmaceutical composition for the treatment or prevention of neural injury.

45. The isolated polynucleotide sequence as claimed in claim **44**, wherein the pharmaceutical composition is selected from the group consisting of ion exchangers, alumina, aluminium stearate, lecithin, serum proteins, buffers, glycine, sorbic acid, potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, disodium hydrogen phosphate, potassium hydrogen phosphate, sodium chloride, zinc salts, colloidal silica, magnesium trisilicate, polyvinyl pyrrolidone, cellulose-based substances, polyethylene glycol, sodium carboxymethylcellulose, polyacrylates, waxes, polyethylene-polyoxypropylene-block polymers, polyethylene glycol and wool fat.

46. A pharmaceutical composition for the treatment or prevention of a neural injury, for promoting survival of neurons and/or for inhibiting cell death, the pharmaceutical composition or medicament including a peptide of 10 to 32 amino acid residues, wherein the peptide comprises at least 10 to 22 arginine residues.

47. The pharmaceutical composition of claim **45**, for use in the treatment or prevention of ischemia, perinatal hypoxia-ischemia, Alzheimer's disease, Huntington's Disease, Multiple Sclerosis, Parkinson's disease, amyotrophic lateral sclerosis, stroke, peripheral neuropathy, spinal cord injury, pain or epilepsy.

48. The pharmaceutical composition of claim **45**, wherein a dosage for administration is from 0.001 mg/kg to 50 mg/kg.

49. The pharmaceutical composition of claim **48**, wherein the dosage is administered orally.

50. The pharmaceutical composition of claim **46**, wherein the pharmaceutical composition further includes carriers selected from the group consisting of ion exchangers, alumina, aluminium stearate, lecithin, serum proteins, buffers, glycine, sorbic acid, potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, disodium hydrogen phosphate, potassium hydrogen phosphate, sodium chloride, zinc salts, colloidal silica, magnesium trisilicate, polyvinyl pyrrolidone, cellulose-based substances, polyethylene glycol, sodium carboxymethylcellulose, polyacrylates, waxes, polyethylene-polyoxypropylene-block polymers, polyethylene glycol and wool fat.

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