# Method for the production of conjugates of insulin-like growth factor-1 and poly(ethylene glycol)

This invention relates to methods for the production of conjugates of insulin-like growth factor-I (IGF-I) with poly(ethylene glycol) (PEG), pharmaceutical compositions containing such conjugates, and methods of use of such conjugates.

## Background of the Invention

Alzheimer's disease (AD) is an increasingly prevalent form of neurodegeneration that accounts for approximately 50%-60% of the overall cases of dementia among people over 65 years of age. It currently affects an estimated 15 million people worldwide and owing to the relative increase of elderly people in the population its prevalence is likely to increase over the next 2 to 3 decades. AD is a progressive disorder with a mean duration of around 8.5 years between onset of clinical symptoms and death. Death of pyramidal neurons and loss of neuronal synapses in brain regions associated with higher mental functions results in the typical symptoms, characterized by gross and progressive impairment of cognitive function (Francis, P.T., et al., J. Neurol. Neurosurg. Psychiatry 66 (1999) 137-147). AD is the most common form of both senile and presenile dementia in the world and is recognized clinically as relentlessly progressive dementia that presents with increasing loss of memory, intellectual function and disturbances in speech (Merritt, A Textbook of Neurology, 6th ed., Lea& Febiger, Philadelphia (1979), pp. 484-489). Neuropathologically, the major hallmarks of AD are the presence of two characteristic lesions: the amyloid senile plaque and neurofibrillary tangle (NFT). While the plaque is deposited extraneuronally, the tangle is observed intraneuronally in the post-mortem brain. One of the major components of the amyloid plaque core is the pathologically deposited small amyloid-beta-peptide (Aß), which is cleaved by secretases from amyloid precursor protein (APP) (Selkoe, D.J., Physiol. Rev. 81 (2001) 741-766; Hardy, J. and Selkoe, D.J., Science 297 (2002) 353-356; Bush, A.I. and Tanzi, R.E., Proc. Natl. Acad. Sci. USA 99 (2002) 7317-7319). Aß, a self-aggregating peptide of 39-43 residues (MW ~4 kDa), is synthesized as part of the larger APP (110-120 kDa). APP is a type I integral membrane glycoprotein with a large N-terminal extracellular domain, a single transmembrane domain and a short cytoplasmic tail. The Aß region spans portions of the extracellular and transmembrane domains of APP. The most common hypothesis for the participation of APP in neuronal cell death in AD is the amyloid hypothesis. This hypothesis postulates that plaque amyloid depositions or partially

aggregated soluble Aß trigger a neurotoxic cascade, thereby causing neurodegeneration similar to AD pathology (Selkoe, D.J., Physiol. Rev. 81 (2001) 741-766; Hardy, J. and Selkoe, D.J., Science 297 (2002) 353-356).

Human insulin-like growth factor I (IGF-I) is a circulating hormone structurally related to insulin. IGF-I was traditionally considered the major mediator of the actions of growth hormone on peripheral tissues. IGF-I consists of 70 amino acids and is also named somatomedin C and defined by SwissProt No. P01343. Use, activity and production are mentioned in, e.g., le Bouc, Y., et al., FEBS Lett. 196 (1986) 108-112; de Pagter-Holthuizen, P., et al., FEBS Lett. 195 (1986) 179-184; Sandberg Nordqvist, A.C., et al., Brain Res. Mol. Brain Res. 12 (1992) 275-277; Steenbergh, P.H., et al., Biochem. Biophys. Res. Commun. 175 (1991) 507-514; Tanner, J.M., et al., Acta Endocrinol. (Copenh.) 84 (1977) 681-696; Uthne, K., et al., J. Clin. Endocrinol. Metab. 39 (1974) 548-554; EP 0 123 228; EP 0 128 733; US 5,861,373; US 5,714,460; EP 0 597 033; WO 02/32449; WO 93/02695.

The regulation of IGF-I function is quite complex. In the circulation, only 0.2 % of IGF-I exists in the free form whereas the majority is bound to IGF-binding proteins (IGFBP's), which have very high affinities to IGF's and modulate IGF-I function. The factor can be locally liberated by mechanisms releasing IGF-I such as proteolysis of IGFBPs by proteases.

IGF-I plays a paracrine role in the developing and mature brain (Werther, G.A., et al., Mol. Endocrinol. 4 (1990) 773-778). In vitro studies indicate that IGF-I is a potent non-selective trophic agent for several types of neurons in the CNS (Knusel, B., et al., J. Neurosci. 10(1990) 558-570; Svrzic, D., and Schubert, D., Biochem. Biophys. Res. Commun. 172 (1990) 54-60), including dopaminergic neurons (Knusel, B., et al., J. Neurosci. 10(1990) 558-570) and oligodendrocytes (McMorris, F.A., and Dubois-Dalcq, M., J. Neurosci. Res. 21 (1988) 199-209; McMorris, F.A., et al., Proc. Natl. Acad. Sci. USA 83 (1986) 822-826; Mozell, R.L., and McMorris, F.A., J. Neurosci. Res. 30 (1991) 382-390)). US 5,093,317 mentions that the survival of cholinergic neuronal cells is enhanced by administration of IGF-I. It is further known that IGF-I stimulate peripheral nerve regeneration (Kanje, M., et al., Brain Res. 486 (1989) 396-398) and enhance ornithine decarboxylase activity US 5,093,317). US 5,861,373 and WO 93/02695 mention a method of treating injuries to or diseases of the central nervous system that predominantly affects glia and/or non-cholinergic neuronal cells by increasing the active concentration(s) of IGF-I and/or analogues thereof in the central nervous system of the patient.

WO 02/32449 is directed to methods for reducing or preventing ischemic damage in the central nervous system of a mammal by administering to the nasal cavity of the mammal a pharmaceutical composition comprising a therapeutically effective amount of IGF-I or biologically active variant thereof. The IGF-I or variant thereof is absorbed through the nasal cavity and transported into the central nervous system of the mammal in an amount effective to reduce or prevent ischemic damage associated with an ischemic event. EP 0 874 641 claims the use of an IGF-I or an IGF-II for the manufacture of a medicament for treating or preventing neuronal damage in the central nervous system, due to AIDS-related dementia, AD, Parkinson's Disease, Pick's Disease, Huntington's Disease, hepatic encephalopathy, cortical- basal ganglionic syndromes, progressive dementia, familial dementia with spastic parapavresis, progressive supranuclear palsy, multiple sclerosis, cerebral sclerosis of Schilder or acute necrotizing hemorrhagic encephalomyelitis, wherein the medicament is in a form for parenteral administration of an effective amount of said IGF outside the blood-brain barrier or blood- spinal cord barrier.

Reduction of brain and serum levels of free IGF-I has been related to the pathogenesis of sporadic and familial forms of AD. Furthermore, IGF-I protects neurons against Aβ-induced neurotoxicity (Niikura, T., et al., J. Neurosci. 21 (2001) 1902-1910; Dore, S., et al., Proc. Natl. Acad. Sci. USA 94 (1997) 4772-4777; Dore, S., et al., Ann. NY Acad. Sci. 890 (1999) 356-364). Recently, it was shown that peripherally administered IGF-I is capable of reducing brain Aβ levels in rats and mice (Carro, E., et al., Nat. Med. 8 (2002) 1390-1397). Furthermore, the study demonstrated that in a transgenic AD mouse model prolonged IGF-I treatment significantly reduced brain amyloid plaque load. These data strongly support the idea that IGF-I is able to reduce brain Aβ levels and plaque-associated brain dementia by clearing Aβ from the brain.

Covalent modification of proteins with poly(ethylene glycol) (PEG) has proven to be a useful method to extend the circulating half-lives of proteins in the body (Hershfield, M.S., et al., N. Engl. J. Med. 316 (1987) 589-596; Meyers, F.J., et al., Clin. Pharmacol. Ther. 49 (1991) 307-313; Delgado, C., et al., Crit. Rev. Ther. Drug Carrier Syst. 9 (1992) 249-304; Katre, Advanced Drug Delivery Reviews 10 (1993) 91-114; EP-A 0 400 472; Monfardini, C., et al., Bioconjugate Chem. 6 (1995) 62-69; Satake-Ishikawa, R., et al., Cell Struct. Funct. 17 (1992) 157-160; Katre, N.V., et al., Proc. Natl. Acad. Sci. USA 84 (1987) 1487-1491; Tsutsumi, Y., et al., Jpn. J. Cancer

Res. 85 (1994) 9-12; Inoue, H., et al., J. Lab. Clin. Med. 124 (1994) 529-536; Chamow, S.M., et al., Bioconjugate Chem. 5 (1994) 133-140).

Other advantages of PEGylation are an increase of solubility and a decrease in protein immunogenicity (Katre, N.V., J. Immunol. 144 (1990) 209-213). A common method for the PEGylation of proteins is the use of poly(ethylene glycol) activated with amino-reactive reagents like N-hydroxysuccinimide (NHS). With such reagents poly(ethylene glycol) is attached to the proteins at free primary amino groups such as the N-terminal α-amino group and the ε-amino groups of lysine residues. However, a major limitation of this approach is that proteins typically contain a considerable amount of lysine residues and therefore the poly(ethylene glycol) groups are attached to the protein in a non-specific manner at all of the free ε-amino groups, resulting in a heterologous product mixture of random PEGylated proteins. Therefore, many NHS-PEGylated proteins are unsuitable for commercial use because of low specific activity. Inactivation results from covalent modification of one or more lysine residues or the N-terminal amino residue required for biological activity or from covalent attachment of the poly(ethylene glycol) residues near or at the active site of the protein. For example, it was found that modification of human growth hormone using NHS-PEGylation reagents reduces the biological activity of the protein by more than 10-fold (Clark, R., et al., J. Biol. Chem. 271 (1996) 21969-21977). Human growth hormone contains 9 lysines in addition to the N-terminal amino acid. Certain of these lysines are located in regions of the protein known to be critical for receptor binding (Cunningham, B.C., et al., Science 254 (1991) 821-825). In addition, the modification of erythropoietin by the use of amino-reactive poly(ethylene glycol) reagents results also in a nearly complete loss of biological activity (Wojchowski, D.M., et al., Biochim. Biophys. Acta 910 (1987) 224-232). Covalent modification of Interferon-α2 with amino-reactive PEGylation reagents results in 40-75% loss of bioactivity (US Patent No. 5,382,657). A similar modification of G-CSF results in greater than 60% loss of activity (Tanaka, H., et al., Cancer Res. 51 (1991) 3710-3714) and of Interleukin-2 in greater than 90% loss of bioactivity (Goodson, R. J., and Katre, N. V., BioTechnology 8 (1990) 343-346).

WO 94/12219 and WO 95/32003 claim polyethylene glycol conjugates comprising PEG and IGF or a cystein mutated IGF, said PEG attached to said mutein at a free cystein in the N-terminal region of the mutein. WO 2004/60300 describes N-terminally PEGylated IGF-I.

The recognition site of the IgA Protease is described as Yaa-Pro.!.Xaa-Pro. Yaa stands for Pro (or rarely for Pro in combination with Ala, Gly or Thr: Pro-Ala, Pro-Gly, or Pro-Thr. Xaa stands for Thr, Ser or Ala (Pohlner, J., et al., Bio/Technology 10 (1992) 799-804; Pohlner, J., et al., Nature 325 (1987) 458-462; and US 5,427,927). Naturally cleavage sites have been identified by Wood, S.G. and Burton J., Infect. Immun. 59 (1991) 1818-1822. Synthetic peptide substrates for the immunoglobulin A1 protease from Neisseria gonorrhoea (type 2) are the autoproteolytic sites Lys-Pro-Ala-Pro.!.Ser-Pro, Val-Ala-Pro-Pro.!.Ser-Pro, Pro-Arg-Pro-Pro.!.Ala-Pro, Pro-Arg-Pro-Pro.!.Ser-Pro, Pro-Arg-Pro-Pro.!.Thr-Pro and the IgA1 Cleavage Sites Pro-Pro-Thr-Pro.!.Ser-Pro and Ser-Thr-Pro-Pro.!.Thr-Pro.

WO 2006/066891 discloses conjugates consisting of an insulin-like growth factor-1 (IGF-I) variant and one or two poly(ethylene glycol) group(s), characterized in that said IGF-I variant has an amino acid alteration at up to three amino acid positions 27, 37, 65, 68 of the wild-type IGF-I amino acid sequence so that one or two of said amino acids is/are lysine and amino acid 27 is a polar aminio acid but not lysine, is conjugated via the primary amino group(s) of said lysine(s) and said poly(ethylene glycol) group(s) have an overall molecular weight of from 20 to 100 kDa is disclosed. Such conjugates are useful for the treatment of neurodegenerative disorders like Alzheimer's Disease. WO 2006/074390 refers to IGF-I fusion polypeptides.

Summary of the Invention

The invention comprises a method for the production of a lysine-PEGylated IGF-I or a lysine-PEGylated IGF-I variant, said variant comprising one or two amino acid(s) selected from the group consisting of lysine 27, 65 and/or 68 substituted independently by another polar amino acid, characterized in

a) cultivating a prokaryotic host cell comprising an expression vector containing a nucleic acid encoding a fusion protein comprising said IGF-I or IGF-I variant N-terminally linked to the C-terminus of a propeptide,

b) whereby said propeptide ends C-terminally with amino acids -Y-Pro, wherein Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro,

c) recovering and PEGylating said fusion protein,

d) cleaving said PEGylated fusion protein with IgA protease, and

e) recovering said PEGylated IGF-I or IGF-I variant.

In one embodiment said method is characterized in that the lysine-PEGylated IGF-I variant is RRK and said variant is monoPEGylated at lysine residue 68 or the lysine-PEGylated IGF-I variant is RKR and said variant is monoPEGylated at lysine residue 65

In another embodiment said method is characterized in that the lysine-PEGylated IGF-I variant is RKK and said variant is mono- or diPEGylated at lysine residues 65 and 68

In another embodiment said method is characterized in that the lysine-PEGylated IGF-I variant is a mixture of RRK, RKR or RKK and said variant is is mono- or diPEGylated at lysine residue(s) 65 and 68.

A further embodiment of the invention is a fusion protein comprising said IGF-I or IGF-I variant N-terminally linked to the C-terminus of a propeptide, characterized in that said propeptide ends C-terminally with amino acids -Y-Pro, wherein Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro. Due to the –Y-Pro sequence the propeptide can be separated by IgA protease treatment from said IGF-I or IGF-I variant.

Preferably the fusion protein according to the invention is characterized by the formula Met-$X_1$-$His_n$-$X_2$-Y-Pro-[IGF-I or IGF-I variant], wherein

- IGF-I denotes human IGF-I and IGF-I variant denotes IGF-I, wherein one or two amino acid(s) selected from the group consisting of lysine 27, 65 and/or 68 is/are substituted independently by another polar amino acid,
- Met denotes methionine,
- $X_1$ is a bond, serine or asparagine,
- His is histidine,
- n is a number from 0 to 10, preferably from 0 to 6,
- $X_2$ is a linker peptide, selected from the group of peptides SEQ ID NO: 6-10,
- Pro is proline, and
- Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro.

Preferably the fusion protein according to the invention is selected from the group consisting of fusion proteins SEQ ID NO: 2-5 and SEQ ID NO: 22-25.

Preferably the propeptide is shown by the formula Met-$X_1$-$His_n$-$X_2$-Y-Pro-, wherein

- Met denotes methionine
- $X_1$ is a bond, serine or asparagine
- His is histidine,
- n is a number from 0 to 10, preferably from 0 to 6,
- $X_2$ is a linker peptide, selected from the group consisting of peptides SEQ ID NO: 6-10,
- Pro is proline, and
- Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro.

The propeptide is C-terminally linked to the N-terminus (glycine) of the IGF-I or IGF-I variant. Preferably the propeptide does not include a lysine residue. The propeptide has preferably a length of up to 30 amino acids. Preferably X1 is a bond. Preferably n is 0 or 6. Preferably X2 is peptide SEQ ID NO:7. Preferably Y is Pro-Arg-Pro.

A further embodiment of the invention is a lysine-PEGylated IGF-I, characterized by not comprising an N-terminal methionine.

A further embodiment of the invention is a lysine-PEGylated IGF-I variant, wherein one or two amino acid(s) selected from the group consisting of lysine 27, 65 and/or 68 is/are substituted independently by another polar amino acid, characterized in that said variant does not comprise an N-terminal methionine.

Preferably said polar amino acid(s) is/are independently arginine, glutamine or asparagine, especially arginine.

Preferred IGF-I variants and variants in the fusion protein are: RKK, RKR, RRK. (IGF-I variants are designated as follows: K65 means that amino acid 65 is lysine, R27 means that amino acid 27 is arginine, etc. An IGF-I variant bearing the amino acids R27, K65, K68 is designated RKK, and the remaining amino acid of said RRK variant are the same as in the IGF-I wildtype of SEQ ID NO.1. Thus RKK is a variant of IGF-I wildtype, which was mutated at position 27 by the exchange from K to R RKR is a variant of IGF-I wildtype, which was mutated at positions 27 and 68 by the exchange from K to R. RRK is a variant of IGF-I wildtype, which was

mutated at positions 27 and 65 by the exchange from K to R. IGF-I wildtype, wherein no amino acid is changed, is designated KKK.

The lysine-PEGylated IGF-I is preferably randomly PEGylated at lysine residues 27, 65 and 68, preferably mono- or diPEGylated (one or two PEG per IGF-I molecule). The lysine-PEGylated IGF-I variant is preferably mono- or diPEGylated at lysine residue(s) 65 and 68, preferably monoPEGylated at K65 or K68. The poly(ethylene glycol) group(s) is/are conjugated to said IGF-I or IGF-I variant via primary amino group(s) of lysine(s).

The method according to the invention comprises the preparation of a lysine-PEGylated IGF-I or IGF-I variant, said poly(ethylene glycol) group(s) having preferably an overall molecular weight of at least 20 kDa per IGF-I or IGF-I variant, more preferably from about 20 to 100 kDa, and especially preferably from 20 to 80 kDa, by reacting the IGF-I fusion protein according to the invention with activated (polyethylene) glycol under conditions such that said (polyethylene) glycol is chemically bound to said IGF-I intermediate via primary lysine amino group(s) of IGF-I or IGF-I variant. Preferably the lysine-PEGylated IGF-I or IGF-I variant is monoPEGylated. The variant is preferably selected from the group consisting of RKK, RKR, RRK regarding amino acid positions 27, 65 and 68, respectively. PEG preferably has an average overall molecular weight of 30 to 45 kDa, especially 30 kDa or 40 kDa.

The invention further comprises pharmaceutical compositions containing a lysine-PEGylated IGF-I or IGF-I variant according to the invention, preferably together with a pharmaceutically acceptable carrier.

The invention further comprises methods for the production of pharmaceutical compositions containing a lysine-PEGylated IGF-I or IGF-I variant according to the invention.

The invention further comprises the use of a lysine-PEGylated IGF-I or IGF-I variant according to the invention for the preparation of a medicament for the treatment of AD.

The invention further comprises methods for the treatment of AD, characterized in that a pharmaceutically effective amount of amino-reactive PEGylated IGF-I or IGF-I variant is administered to a patient in need of such treatment, preferably in one to two applications per week.

Detailed Description of the Invention

It was surprisingly found that IgA protease, preferably IgA protease from Neisseria gonorrhoea, is capable of cleaving the amino acid sequence Y-Pro.!.Gly-Pro. Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro. Preferably useful as cleavage site is Pro-Pro.!.Gly-Pro (SEQ ID NO:15) or Pro-Arg-Pro-Pro.!.Gly-Pro (SEQ ID NO:11) (.!. : cleavage position). The IgA protease cleavage site for the process according to the present invention has the amino acid consensus sequence Y-Pro.!.Gly-Pro, whereby Gly-Pro are the first two amino acids of IGF-I. Y preferably represents an amino acid sequence which ends with the amino acid(s) Pro, Pro-Ala, Arg-Pro or Pro-Arg-Pro. Such Y amino acid sequences, especially Pro-Arg-Pro can be prolonged by a further Ala or Pro-Ala group, as e.g. in Ala-Pro-Arg-Pro (SEQ ID NO:12) or Pro-Ala-Pro-Arg-Pro (SEQ ID NO:13). Particularly preferred are the cleavage amino acid sequences Pro-Ala-Pro.!.Gly-Pro (SEQ ID NO:14), Pro-Pro-!.Gly-Pro (SEQ ID NO:15), Pro-Arg-Pro-Pro.!. Gly-Pro (SEQ ID NO:16), Ala-Pro-Arg-Pro-Pro.!.Gly-Pro (SEQ ID NO:17) or Pro-Ala-Pro-Arg-Pro-Pro.!.Gly-Pro (SEQ ID NO:18).

In accordance with the present invention the term "IgA protease" includes proteases which specifically cleave IgA and which are described for example by Kornfeld, S.J. and Plaut, A.G. in Rev. Infekt. Dis. 3 (1981) 521-534 as e.g. IgA1 protease from Neisseria gonorrhoea (type 2). Recombinant IgA proteases such as those described in DE-A 36 22 221; Koomey, J.M., et al., Proc. Natl. Acad. Sci. USA 79 (1982) 7881-7885; Bricker, J., et al., Proc. Natl. Acad. Sci. USA 80 (1983) 2681- 2685; Pohlner, J., et al., Nature 325 (1987) 458- 462; and Halter, R., et al., EMBO J. 3 (1984) 1595-1601 are also just as suitable. Preferably said IgA protease is IgA protease from Neisseria gonorrhoea, preferably type 2. Preferably said IgA1 protease from Neisseria gonorrhoea (type 2) has the sequence SEQ ID NO:26.

The gene encoding the fusion protein is preferably placed under the control of suitable (preferably inducible) expression signals so that fusion proteins can be produced according to the requirements. Suitable prokaryotic or eukaryotic (plant as well as animal) cells can be used as host cells for the production of protein fusions; cell- free systems are, however, also possible.

A preferred embodiment of the process according to the present invention is characterized in that a host cell is transformed with a recombinant DNA or a recombinant vector, in which the DNA or the vector contains at least one copy of a

gene which codes for a fusion protein according to the invention and the transformed cell is cultured in a suitable medium, the gene coding for the fusion protein is made to express in the transformed cell, the fusion protein is PEGylated and subsequently cleaved with IgA protease and the PEGylated IGF-I or IGF-I variant is isolated.

The expression of the fusion protein according to the invention can, for example, be improved at the DNA level by fusion with fragments of lysine-free beta-galactosidase gene, i.e., Y contains a part of a lysine-free beta-galactosidase protein. Other alternatives for increasing the expression of the fusion protein are known to the expert. The purification and separation of the expression product can be facilitated by fusion with other polypeptides, in particular, with polypeptides or proteins that are highly charged (e.g. poly(Lys, Arg)) or which can bind to particular substances with high affinity (e.g. streptavidin) (see e.g. EP-A 0 089 626, EP-A 0 306 610). Especially preferred linker peptides are peptides SEQ ID NO: 6-10, preferably N-terminally preceded by SHHHHHH (SEQ ID NO:19), NHHHHHH (SEQ ID NO:20) or HHHHHH (SEQ ID NO:21).

The present invention also provides a (recombinant) nucleic acid which codes for a fusion protein according to the present invention and in which an IgA protease cleavage site is incorporated in the junction region between the propeptide and the IGF-I or IGF-I variant.

A recombinant DNA according to the present invention can be obtained in a manner known to one skilled in the area of molecular biology. For this a vector which contains a DNA sequence coding for the amino acid sequence of the IGF-I or IGF-I variant is usually cleaved with restriction endonuclease(s) in the region of the 5' end of this gene and religated with oligonucleotides which contain the desired sequence.

In addition, the invention also provides a recombinant vector which contains at least one copy of a recombinant DNA according to the present invention. Vectors which are suitable as a basis for protein expression in prokaryotic organisms are known to the expert. This vector is preferably one which allows a high expression of the recombinant DNA according to the present invention. The recombinant DNA on the vector is preferably under the control of an inducible expression signal (e.g. . lambda., tac, lac or trp promoter).

The vector according to the present invention can be present extrachromosomally (e.g. plasmid) as well as integrated in the genome of the host organism (e.g. bacteriophage lambda). The vector according to the present invention is preferably a plasmid. Vectors which are suitable in each case for gene expression in a particular host organism are known to one skilled in the area of molecular biology. It can be a eukaryotic vector, but preferably a prokaryotic vector. Examples of suitable vectors for the expression of the DNA according to the present invention in prokaryotes are, for instance, commercially available pUC and pUR vectors.

The invention also provides a cell, preferably a prokaryotic cell, particularly preferably an E. coli cell, which is transformed with the recombinant DNA according to the present invention or/and with a recombinant vector according to the present invention.

When the fusion protein is expressed in prokaryotes, sparingly soluble aggregates (refractile bodies, inclusion bodies) are formed which are inactive. Therefore the fusion protein must be transformed into its active form. Using procedures which are familiar to those skilled in the art (cf. e.g. EP-A 0 219 874, EP A 0 114 506, WO 84/03711) first a solubilization is carried out by addition of denaturing agents which is followed by renaturation and, if desired, further purification steps. The treatment of the fusion protein with IgA protease takes place after PEGylation of the fusion protein.

The conditions required for the treatment of PEGylated IGF-I or IGF-I variant to be cleaved with IgA proteases are not critical. In this process it is, however, preferred that the ratio by weight of PEGylated IGF-I or IGF-I variant to IgA protease is 1:1 to 500:1, preferably, 100:1. The reaction preferably takes place in a buffered aqueous solution of pH 6.5 to 8.5. The buffer concentration is preferably in the range between 50 and 500 mmol/l if desired, with addition of 0-100 mmol/l sodium chloride. The cleavage is preferably carried out at room temperature for at least 60 min up to 5 days, preferably between 24 – 72 h.

After solubilization, renaturation, PEGylation and cleavage with IgA protease the PEGylated cleavage product obtained in this way is preferably purified by means of ion exchange chromatography, hydrophobic interaction chromatography and/or fractionation by size. The PEGylated IGF-I or IGF-I variant produced in this way is free of methionine in position -1 and preferably free of other proteins, like non-

PEGylated IGF-I or IGF-I variant, and preferably free of N-terminal PEGylated propeptide, by 5 %(w/w) or lower.

"PEGylated IGF-I or IGF-I variant" or "amino-reactive PEGylation" as used herein means that an IGF-I or IGF-I variant is covalently bonded to poly(ethylene glycol) groups by amino-reactive coupling. The PEG group(s) is/are attached at the sites of the IGF-I or IGF-I variant molecule that are the primary ε-amino groups of the lysine side chains. It is further possible that PEGylation occurs in addition on the N-terminal α-amino group of the propeptide. Due to the synthesis method and fusion protein used, PEGylated IGF-I or IGF-I variant can consist of a mixture, whereby the sites of PEGylation can be different in different molecules or can be substantially homogeneous with regard to the amount of poly(ethylene glycol) side chains per molecule and/or the site of PEGylation in the molecule. Preferably the IGF-I or IGF-I variants are mono- and/or diPEGylated.

Amino-reactive PEGylation as used herein designates a method of randomly attaching poly(ethylene glycol) chains to primary lysine amino group(s) of the IGF-I or IGF-I variant by the use of reactive (activated) poly(ethylene glycol), preferably by the use of N-hydroxysuccinimidyl esters of, preferably, methoxypoly(ethylene glycol). The coupling reaction attaches poly(ethylene glycol) to reactive primary ε-amino groups of lysine residues and optionally the α-amino group of the N-terminal amino acid of the fusion protein. Such amino group conjugation of PEG to proteins is well known in the art. For example, review of such methods is given by Veronese, F.M., Biomaterials 22 (2001) 405-417. According to Veronese, the conjugation of PEG to primary amino groups of proteins can be performed by using activated PEGs which perform an alkylation of said primary amino groups. For such a reaction, activated alkylating PEGs, for example PEG aldehyde, PEG-tresyl chloride or PEG epoxide can be used. Further useful reagents are acylating PEGs such as hydroxysuccinimidyl esters of carboxylated PEGs or PEGs in which the terminal hydroxy group is activated by chloroformates or carbonylimidazole. Further useful PEG reagents are PEGs with amino acid arms. Such reagents can contain the so-called branched PEGs, whereby at least two identical or different PEG molecules are linked together by a peptidic spacer (preferably lysine) and, for example, bound to IGF-I or IGF-I variant as activated carboxylate of the lysine spacer.

"PEG or poly(ethylene glycol)" as used herein means a water soluble polymer that is commercially available or can be prepared by ring-opening polymerization of

ethylene glycol according to methods well known in the art (Kodera, Y., et al., Progress in Polymer Science 23 (1998) 1233-1271; Francis, G.E., et al., Int. J. Hematol. 68 (1998) 1-18). The term "PEG" is used broadly to encompass any polyethylene glycol molecule, wherein the number of ethylene glycol units is at least 460, preferably 460 to 2300 and especially preferably 460 to 1840 (230 PEG units refers to an molecular weight of about 10 kDa). The upper number of PEG units is only limited by solubility of the lysine-PEGylated IGF-I or IGF-I variant. Usually PEGs which are larger than PEGs containing 2300 units are not used. Preferably, a PEG used in the invention terminates on one end with hydroxy or methoxy (methoxy PEG, mPEG) and is on the other end covalently attached to a linker moiety via an ether oxygen bond. The PEG polymer is either linear or branched. Preferably the PEG polymer is branched. Branched PEGs are described, e.g., in Veronese, F.M., et al., Journal of Bioactive and Compatible Polymers 12 (1997) 196-207. Useful PEG reagents are, e.g., available from Nektar Therapeutics (www.nektar.com). Branched PEGs can be prepared, for example, by the addition of polyethylene oxide to various polyols, including glycerol, pentaerythriol, and sorbitol. For example, a four-armed branched PEG can be prepared from pentaerythriol and ethylene oxide. Branched PEGs usually have 2 to 8 arms and are described in, for example, EP-A 0 473 084 and US Patent No. 5,932,462. Especially preferred are PEGs with two PEG side-chains linked via the primary amino group of a lysine (abbreviated as PEG2) (Monfardini, C., et al., Bioconjugate Chem. 6 (1995) 62-69).

Any molecular mass for a PEG can be used as practically desired, e.g., from about 20 kDaltons (Da) to 100 kDa (n is 460 to 2300). The number of repeating units "n" in the PEG is approximated for the molecular mass described in Daltons. For example, if two PEG molecules are attached to a linker, where each PEG molecule has the same molecular mass of 10 kDa (each n is about 230), then the total molecular mass of PEG on the linker is about 20 kDa. The molecular masses of the PEG attached to the linker can also be different, e.g., of two molecules on a linker one PEG molecule can be 5 kDa and one PEG molecule can be 15 kDa. Molecular mass means always average molecular mass.

In the examples below, some preferred reagents for the production of amino-reactive IGF-I or IGF-I variants are described. It is understood that modifications, for example, based on the methods described by Veronese, F.M., Biomaterials 22

(2001) 405-417, can be made in the procedures as long as the process results in lysine-PEGylated IGF-I or IGF-I variants according to the invention.

The invention provides methods for the production of PEGylated forms of IGF-I or IGF-I variant with improved properties. Such lysine-PEGylated IGF-I or IGF-I variants contain linear or branched PEG randomly attached thereto, whereby the overall molecular weight of all PEG groups in the lysine-PEGylated IGF-I or IGF-I variant is preferably about 20 to 80 kDa. It is obvious to a person skilled in the art that small deviations from this range of molecular weight are possible as long as the PEGylated IGF-I or IGF-I variant does show activity in lowering Abeta peptide levels in the brain. Also PEG having molecular weights of more than 80 kDa results in higher bioavailability. However, it is expected that such activity decreases as the molecular weight increases due to reduced IGF-I receptor activation and blood-brain barrier transport. Therefore, the range of 20 to 100 kDa for the molecular weight of PEG has to be understood as the optimized range for a lysine-PEGylated IGF-I or IGF-I variant useful for an efficient treatment of a patient suffering from AD.

Preferably produced is a monoPEGylated IGF-I variant, selected from the group consisting of RKK, RKR and RRK wherein the branched PEG group has a molecular weight of 30-45, preferably 40-45 kDa (about 920 PEG units). For example, based on an average molecular weight of 44 kDa for PEG and a molecular weight of 7.6 kDa for IGF-I, the calculated average molecular weight for such a monoPEG-IGF-I is about 51.6 kDa. Especially preferred is the use of an N-hydroxysuccinimidyl activated branched PEG ester (mPEG2-NHS) of a molecular weight of 40 kDa (Monfardini, C., et al., Bioconjugate Chem. 6 (1995) 62-69; Veronese, F.M., et al., J. Bioactive Compatible Polymers 12 (1997) 197-207; US Patent 5,932,462). Also preferably produced is a monoPEGylated IGF-I wherein the PEG has an average molecular weight of 30 or 40 kDa.

As used herein, "molecular weight" means the mean molecular weight of the PEG.

The following PEGylated forms of IGF-1 or IGF-I variants are preferred products and available by the methods according to the invention:

- K68 monoPEGylated IGF-I variant, preferably RRK or RKK variant, more preferably RRK variant, wherein the PEG group has a molecular weight of 20 to 80 kDa (460 to 1840 PEG units);

- K 65 monoPEGylated IGF-I variant, preferably RKR or RKK variant, more preferably RKR variant, wherein the PEG group has a molecular weight of 20 to 80 kDa (460 to 1840 PEG units);
- diPEGylated IGF-I variant, preferably RKK variant, wherein the PEG groups have a molecular weight of about 10 -50 kDa (230 to 1150 PEG units) each; and mixtures thereof;
- K 68 monoPEGylated IGF-I variant, preferably RRK or RKK variant, more preferably RRK variant, comprising a PEG2 group of a molecular weight of 40 kDa;
- K 65 monoPEGylated IGF-I variant, preferably RKR or RKK variant, more preferably RKR variant, comprising a PEG2 group of a molecular weight of 40 kDa;
- monoPEGylated IGF-I, wherein the PEG group has a molecular weight of 20 to 80 kDa (460 to 1840 PEG units);
- diPEGylated IGF-I, wherein the PEG groups have a molecular weight of about 10 -50 kDa (230 to 1150 PEG units) each;
- monoPEGylated IGF-I, comprising a PEG2 group of a molecular weight of 40 kDa.

PEGylated IGF-I or IGF-I variants are substantially homogeneous. The preparation may contain small amounts of unreacted (i.e., lacking PEG group) protein. As ascertained by peptide mapping purity of the variant is at least 90%(w/w). Further purification of such preparations, including the separation of mono- and/or diPEGylated IGF-I or IGF-I variants, can be performed by usual purification methods, preferably by size exclusion chromatography, hydrophobic interaction chromatography and/or by ion exchange chromatography, especially by cationic exchange chromatography.

"MonoPEGylated" as used herein means that IGF-I or IGF-I variant is PEGylated at only one lysine per IGF-I or IGF-I variant molecule.

"Activated PEGs or activated PEG reagents" are well-known in the state of the art. Preferably there are used electrophilically activated PEGs such as alkoxybutyric acid succinimidyl esters of poly(ethylene glycol) ("lower alkoxy-PEG-SBA") or alkoxypropionic acid succinimidyl esters of poly(ethylene glycol) ("lower alkoxy-PEG-SPA") or N-hydroxysuccinimide activated PEGs. Any conventional method of reacting an activated ester with an amine to form an amide can be

utilized. In the reaction of the activated PEG with IGF-I, the exemplified succinimidyl ester is a leaving group causing the amide formation. The use of succinimidyl esters to produce conjugates with proteins is disclosed in US Patent No. 5,672,662.

The reaction conditions used have an influence on the relative amount of differently PEGylated IGF-I or IGF-I variants. By manipulating the reaction conditions (e.g., ratio of reagents, pH, temperature, protein concentration, time of reaction etc.), the relative amounts of the different PEGylated species can be varied. Preferably the reaction is performed in a buffered aqueous solution pH 8-10, optionally containing up to 30% (v/v) ethanol. The molar protein: PEG ration is preferably 1:1 to 1:6, preferably 1:2 to 1:5. Reaction temperature and reaction time can be varied according to the knowledge of a skilled artisan, whereby high temperature and long reaction time results in increased PEGylation. If monoPEGylated proteins are produced, it is therefore preferred to work between 4°C and 22°C and for up to 30 minutes or up to 60 minutes. When the PEGylation reagent is combined with IGF-I or IGF-I variant in a reaction buffer which preferably consist of 50mM sodium borate and 25 % ethanol at a pH of about 9.0 – 9.5, a protein:PEG ratio of about 1:3 to 1:4, and a reaction temperature of 4°C, a mixture of mono-, di-, and trace amounts of the tri-PEGylated species are produced depending on the presence of Lys residues in the protein .

Lysine-PEGylated IGF-I or IGF-I variants according to the invention may be prepared by covalently reacting a primary lysine amino group of an IGF-I or IGF-I variant with a bifunctional reagent to form an intermediate with an amide linkage and covalently reacting the intermediate containing amide linkage with an activated poly(ethylene glycol) derivative to form a lysine-PEGylated IGF-I or IGF-I variant. In the foregoing process, the bifunctional reagent is preferably N-succinimidyl-S-acetylthiopropionate or N-succinimidyl-S-acetylthioacetate, and the activated poly(ethylene glycol) derivative is preferably selected from the group consisting of iodo-acetyl-methoxy-PEG, methoxy-PEG-vinylsulfone, and methoxy-PEG-maleimide.

Activated PEG derivatives are known in the art and are described in, for example, Morpurgo, M., et al., J. Bioconjugate Chem. 7 (1996) 363-368 for PEG-vinylsulfone. Linear chain and branched chain PEG species are suitable for the preparation of the compounds of formula I. Examples of reactive PEG reagents are iodo-acetyl-methoxy-PEG and methoxy-PEG-vinylsulfone. The use of these iodo-

activated substances is known in the art and is described, e.g., by Hermanson, G.T., in Bioconjugate Techniques, Academic Press, San Diego (1996), pp. 147-148.

A "polar amino acid" as used herein refers to an amino acid selected from the group consisting of cysteine (C), aspartic acid (D), glutamic acid (E), histidine (H), asparagine (N), glutamine (Q), arginine (R), serine (S), and threonine (T). Lysine is also a polar amino acid, but excluded, as lysine is replaced according to the invention. Arginine is preferably used as polar amino acid.

Pharmaceutical Formulations

The PEGylated IGF-I or IGF-I variant produced according to the invention provides improved stability in the circulation enabling a sustained access to IGF-I receptors throughout the body with low application intervals.

The compounds of the present invention can be formulated according to methods for the preparation of pharmaceutical compositions, which methods are known to the person skilled in the art. For the production of such compositions, a PEGylated IGF-I or IGF-I variant according to the invention is combined in a mixture with a pharmaceutically acceptable carrier, preferably by dialysis or diafiltration against an aqueous solution containing the desired ingredients of the pharmaceutical compositions. Such acceptable carriers are described, for example, in Remington's Pharmaceutical Sciences, 18th edition, 1990, Mack Publishing Company, edited by Oslo et al. (e.g. pp. 1435-1712). Typical compositions contain an effective amount of the substance according to the invention, for example from about 0.1 to 100 mg/ml, together with a suitable amount of a carrier. The compositions may be administered parenterally. The PEGylated IGF-I or IGF-I variant according to the invention is administered preferably via intraperitoneal, subcutaneous, intravenous or intranasal application.

The pharmaceutical formulations according to the invention can be prepared according to known methods in the art. Usually, solutions of PEGylated IGF-I or IGF-I variant are dialyzed or diafiltrated against the buffer intended to be used in the pharmaceutical composition and the desired final protein concentration is adjusted by concentration or dilution.

The following examples and figures are provided to aid the understanding of the present invention, the true scope of which is set forth in the appended claims. It is understood that modifications can be made in the procedures set forth without

departing from the spirit of the invention. Names of the amino acids are abbreviated using either the one letter code (e.g. R) or the three letter code (e.g. Arg).

Sequence Listing

| | |
|---|---|
| SEQ ID NO: 1 | amino acid sequence of human IGF-I (amino acids 49-118 from SwissProt P01343). |
| SEQ ID NO: 2 | amino acid sequence of fusion protein px3036_IAG_R K27R K65R K68 |
| SEQ ID NO: 3 | amino acid sequence of fusion protein px3036_IAEE_F1 K27R K65R K68 |
| SEQ ID NO: 4 | amino acid sequence of fusion protein px3036_IAFX_F1 K27R K65R K68 |
| SEQ ID NO: 5 | amino acid sequence of fusion protein px3036_IAFX_F2 K27R K65R K68 |
| SEQ ID NO: 6-10 | linker |
| SEQ ID NO: 11-18 | cleavage sequences |
| SEQ ID NO: 19-21 | others |
| SEQ ID NO: 22 | amino acid sequence of fusion protein px3036_IAG_R K27R K65 K68R |
| SEQ ID NO: 23 | amino acid sequence of fusion protein px3036_IAEE_F1 K27R K65 K68R |
| SEQ ID NO: 24 | amino acid sequence of fusion protein px3036_IAFX_F1 K27R K65 K68R |
| SEQ ID NO: 25 | amino acid sequence of fusion protein px3036_IAFX_F2 K27R K65 K68R |
| SEQ ID NO: 26 | amino acid sequence of an IgA1 protease from Neisseria gonorrhoea (type 2) |

Description of the Figures

Fig 1: **Peptide analysis of monoPEGylated fusion protein.**
SDS-PAGE analysis of folded fusion protein before and after PEGylation. Lane 1, mixture of standard protein (bovine lung aprotinin, 6.0 kDa; chicken egg white lysozyme, 14.4 kDa; soybean trypsin inhibitor, 21.5 kDa; bovine erythrocyte carbonic anhydrase, 31.0 kDa; porcine muscle lactate dehydrogenase, 36.5 kDa; bovine liver glutamic dehydrogenase, 55.4 kDa; bovine serum albumin, 66.3 kDa; rabbit muscle phosphorylase b, 97.4 kDa;

E.coli ß-galactosidase, 97.4 kDa; rabbit muscle myosin, 200 kDa); lane 2, pro-IGF-I before pegylation; lane 3, pro-IGF-I after pegylation.

Fig. 2: **Peptide analysis of monoPEGylated IGF-I variant.**
SDS-PAGE analysis of pegylated fusion protein before and after IgA cleavage. Lane 1, mixture of standard protein (same as in Figure 1); lane 2, reaction mix before IgA protease cleavage; lane 3, reaction mix after IgA protease cleavage.

Fig. 3: **SDS PAGE.**
SDS-PAGE analysis of folded fusion protein before and after PEGylation. Lane 1, mixture of standard protein (same as in Figure 1); lane 2, reaction mix before IEC; lane 3, flow through of IEC; lanes 4-19, single eluted fractions from IEC.

Fig. 4: **In vivo brain Abeta lowering of PEG-RRK in B6.152H mice.**
Double-transgenic B6.152H mice aged 9-10 months were treated with vehicle (NaCl) or with PEG-RRK (5 µg/kg s.c., twice-a-week) for 14 days. Soluble brain extracts were prepared and APP, Abeta and Actin levels evaluated as described. The ratios APP/Actin, Abeta/Actin and Abeta/APP were calculated, are expressed as % of control. A, APP/Actin; B, Abeta/Actin, C, Abeta/APP. Upper graphs show single animal data points, lower graphs show bar representation (means ± SEM) including statistical differences (*, $p<0.05$; **, $p<0.01$ vs. untreated control, n=10).

## Examples

### Example 1

The following mutants (comprising IGF-I - variant RRK) with the propeptides of (formula I) were produced):

| Mutant | $X_1$ | $X_2$ | n | Y |
|---|---|---|---|---|
| Px3036_ IAG K27R K65R K68 | none | KAKRFKKH | 6 | PRPP |
| Px3036_IAG_R K27R K65R K68 | none | RARRFRRH | 6 | PRPP |
| Px3036_IAEE_F1 K27R K65R K68 | S | NTEHNREH | 6 | PRPP |
| Px3036_IAFX_F1 K27R K65R K68 | N | IEGRH | 6 | PRPP |
| Px3036_IAFX_F2 K27R K65R K68 | N | TEFENIEH | 6 | PRPP |

**Preparation of K68-mono-pegylated IGF-I-variant (RRK variant)**

The expression vector and the E. coli strain used are described in EP 0 972 838. From an E. coli clone, expressing fusion protein px3036_IAG_R K27R K65R K68, px3036_IAEE_F1 K27R K65R K68, px3036_IAFX_F1 K27R K65R K68 or

px3036_IAFX_F2 K27R K65R K68, grown on selective agar plate, one inoculating loop was transferred to (100 ml) selective medium and cultivated for 13 h at 37°C to an optical density (578 nm) of 2 – 4 . This culture was stored on ice for the next 6 hours prior to the automated inoculation of the main culture which was performed at 37°C. The expression of IGF-I mutant was initiated at an optical density (578 nm) of 50 with the addition of 1.0 mM IPTG. The overall fermentation lasts up to 16 hours. The amount of protein was determined densitometrically by comparing the volumetric intensity of the protein band of the product with the band of an IGF standard on a SDS-PAGE gel. The culture broth was harvested by centrifugation.

To obtain purified inclusion body (IB) material, the harvested biomass out of standard fermentation was treated with the following procedure: biomass was resuspended with TrisMgSO$_4$ buffer pH7 and supplemented with 0.3 g/100 g bio dry weight. Lysozyme and 5 U/1 g bio dry weight Benzonase were incubated for 20 min and homogenized. 30 U/1 g bio dry weight Benzonase was added and incubated for 60 min. at 37 °C. 0.5 L Brij-buffer / liter was added and incubated for 30 min. at RT. After centrifugation the pellet was resuspended in 300 ml Tris-EDTA-buffer/100 g bio wet weight (purified IB wet weight), incubated for 30 min. at RT and centrifugated. 1g IBs/liter were solubilized at room temperature in 6.8 M guanidine-HCl, 0.1 M TrisHCl, 0.1 M DTT, pH 8.5 overnight. The turbid solution was dialyzed at 4°C against 6.8 M guanidine-HCl, 0.1 M TrisHCl, pH 8.0. After dialysis insoluble components were removed by centrifugation. Folding was performed by 50-fold dilution of the pro-IGF-I solution into 0.8 M arginine, 0.1 M TrisHCl, 0.1 M guanidine-HCl, 1 mM GSH, 1 mM GSSG, pH 8.5 at room temperature. After two hours the solution was supplemented with 2 M sodium chloride, filtered and applied at a flow rate of 10 ml/min to a HIC column (Butyl Sepharose 4 Fast Flow; GE, Amersham Biosciences), which had been equilibrated at room temperature with buffer containing 2 M NaCl, 0.8 M arginine, 0.1 M TrisHCl, 0.1 M guanidine-HCl, pH 8.5. The column was washed with equilibration buffer till baseline was achieved and then eluted with ten column volumes of a linear gradient starting with equilibration buffer and ending with buffer containing 0.1 M TrisHCl, 5% ethylene glycol, pH 8.5. Eluted fractions were analyzed by reversed phase high performance chromatography (rpHPLC). Fractions that contained protein with correctly formed SS-bridges were pooled. The pool was dialyzed at 4°C against 50 mM sodium borate, pH 9.0. NHS activated 40 kDa branched PEG (N-hydroxysuccinimide (NHS) ester of mPEG MW 20'000 (mPEG2NHS, US 5,932,462, Nektar Shearwater Polymers, Huntsville, AL) was

solubilized in ice-cold 2 mM HCl and immediately added to the dialyzed protein solution (molar PEG-reagent / protein ratio 2:1). After 1 h and 2 h incubation on ice the same amount of acidic mPEG2-NHS solution was added to the protein/PEG reaction mix. After a third addition of the same amount of acidic mPEG2-NHS solution (overall 6-fold molar excess of PEG reagent) the reaction was incubated on ice for an additional hour. The reaction was stopped by the addition of solid ammonium chloride and incubation for another 45 minutes and then adjusted to pH 8.0 (see Figure 1). The protein/PEG reaction mix was supplemented with IgA1 protease from Neisseria gonorrhoea (type 2) (w/w ratio 1:50) and incubated over night at room temperature (see Figure 2). The reaction mix was diluted 1:2 with 50 mM acetic acid pH 4.5 and then applied to a cation IEC column (MacroCap SP support; GE, Amersham Biosciences, Uppsala, Sweden), which had been equilibrated with 50 mM acetic acid. The column was washed till baseline was reached and then eluted with 20 column volumes of a linear gradient starting with 50 mM acetic acid and ending with 50 mM acetic acid supplemented with 1 M sodium chloride. Eluted fractions were analyzed by SDS-PAGE. Fractions containing a single band with an estimated relative molecular size of about 60 kDa were pooled as K68-monoPEGylated IGF-I (see Figure 3). Identity of K68-monoPEGylated IGF-I was verified by analytical size exclusion chromatography (SEC) with static light scattering detection, MS analysis of tryptic digests, MS analysis of Asp-N digests and analytical cation IEC. No other pegylation isovariant besides K68-monoPEGylated IGF-I could be found.

Example 2

The following mutants (comprising IGF-I - variant RKR) with the propeptides of (formula I) were produced):

| Mutant | $X_1$ | $X_2$ | n | Y |
|---|---|---|---|---|
| Px3036_ IAG K27R K65 K68R | none | KAKRFKKH | 6 | PRPP |
| Px3036_IAG_R K27R K65 K68R | none | RARRFRRH | 6 | PRPP |
| Px3036_IAEE_F1 K27R K65 K68R | S | NTEHNREH | 6 | PRPP |
| Px3036_IAFX_F1 K27R K65 K68R | N | IEGRH | 6 | PRPP |
| Px3036_IAFX_F2 K27R K65 K68R | N | TEFENIEH | 6 | PRPP |

Preparation of K65-mono-pegylated IGF-I-variant (RKR variant)

The expression vector and the E. coli strain to use are described in EP 0 972 838. From an E. coli clone, expressing fusion protein px3036_IAG_R K27R K65 K68R, px3036_IAEE_F1 K27R K65 K68R, px3036_IAFX_F1 K27R K65 K68R or

px3036_IAFX_F2 K27R K65 K68R, grown on selective agar plate, one inoculating loop is transferred to (100 ml) selective medium and cultivated for 13 h at 37°C to an optical density (578 nm) of 2 – 4 . This culture is stored on ice for the next 6 hours prior to the automated inoculation of the main culture which is performed at 37°C. The expression of IGF-I mutant is initiated at an optical density (578 nm) of 50 with the addition of 1.0 mM IPTG. The overall fermentation lasts up to 16 hours. The amount of protein is determined densitometrically by comparing the volumetric intensity of the protein band of the product with the band of an IGF standard on a SDS-PAGE gel. The culture broth is harvested by centrifugation.

To obtain purified inclusion body (IB) material, the harvested biomass out of standard fermentation is treated with the following procedure: biomass is resuspended with TrisMgSO4 buffer pH7, and supplemented with 0.3 g/100 g bio dry weight Lysozyme and 5 U/1 g bio dry weight Benzonase are incubated for 20 min and homogenized. 30 U/1 g bio dry weight Benzonase is added and incubated for 60 min. at 37 °C. 0.5 L Brij-buffer / liter is added and incubated for 30 min. at RT. After centrifugation the pellet is resuspended in 300 ml Tris-EDTA-buffer/100 g bio wet weight (purified IB wet weight), incubated for 30 min. at RT and centrifugated. 1g IBs/liter are solubilized at room temperature in 6.8 M guanidine-HCl, 0.1 M TrisHCl, 0.1 M DTT, pH 8.5 overnight. The turbid solution is dialyzed at 4°C against 6.8 M guanidine-HCl, 0.1 M TrisHCl, pH 8.0. After dialysis insoluble components are removed by centrifugation. Folding is performed by 50-fold dilution of the pro-IGF-I solution into 0.8 M arginine, 0.1 M TrisHCl, 0.1 M guanidine-HCl, 1 mM GSH, 1 mM GSSG, pH 8.5 at room temperature. After 2 to 48 hours, preferably after 2 to 24 hours the solution is supplemented with 2 M sodium chloride, filtered and applied at a flow rate of 10 ml/min to a HIC column (Butyl Sepharose 4 Fast Flow; GE, Amersham Biosciences), which is equilibrated at room temperature with buffer containing 2 M NaCl, 0.8 M arginine, 0.1 M TrisHCl, 0.1 M guanidine-HCl, pH 8.5. The column is washed with equilibration buffer till baseline is achieved and then eluted with ten column volumes of a linear gradient starting with equilibration buffer and ending with buffer containing 0.1 M TrisHCl, 5% ethylene glycol, pH 8.5. Eluted fractions are analyzed by reversed phase high performance chromatography (rpHPLC). Fractions that contained protein with correctly formed SS-bridges were pooled. The pool is dialyzed at 4°C against 50 mM sodium borate, pH 9.0. NHS activated 40 kDa branched PEG (N-hydroxysuccinimide (NHS) ester of mPEG MW 20'000 (mPEG2NHS, US 5,932,462, Nektar Shearwater Polymers, Huntsville, AL) is solubilized in ice-

cold 2 mM HCl and immediately added to the dialyzed protein solution (molar PEG-reagent / protein ratio 2:1). After 1 h and 2 h incubation on ice the same amount of acidic mPEG2-NHS solution is added to the protein/PEG reaction mix. After a third addition of the same amount of acidic mPEG2-NHS solution (overall 6-fold molar excess of PEG reagent) the reaction is incubated on ice for an additional hour. The reaction is stopped by the addition of solid ammonium chloride and incubation for another 45 minutes and then adjusted to pH 8.0 (see Figure 1). The protein/PEG reaction mix is supplemented with IgA1 protease from Neisseria gonorrhoea (type 2) (w/w ratio 1:50) and incubated over night at room temperature (see Figure 2). The reaction mix is diluted 1:2 with 50 mM acetic acid pH 4.5 and then applied to a cation IEC column (MacroCap SP support; GE, Amersham Biosciences, Uppsala, Sweden), which is equilibrated with 50 mM acetic acid. The column is washed till baseline is reached and then eluted with 20 column volumes of a linear gradient starting with 50 mM acetic acid and ending with 50 mM acetic acid supplemented with 1 M sodium chloride. Eluted fractions are analyzed by SDS-PAGE. Fractions containing a single band with an estimated relative molecular size of about 60 kDa are pooled as K65-monoPEGylated IGF-I. Identity of K65-monoPEGylated IGF-I is verified by analytical size exclusion chromatography (SEC) with static light scattering detection, MS analysis of tryptic digests, MS analysis of Asp-N digests and analytical cation IEC.

Example 3

**Reduction of brain soluble Abeta by K68 monoPEGylated IGF-I-variant RRK *in vivo***

For evaluation of potency of K68 monoPEGylated IGF-I variant RRK (40kD, PEG2) (PEG-RRK) on lowering soluble Abeta levels, 9-10 months old B6.152H mice (doubletransgenic mice expressing human APP and PS2 mutants) with heavy amyloid plaque load were repeatedly treated by twice-a-week s.c. injection of 5 µg/kg PEG-RRK. Cortical APP, Abeta and Actin levels were detected after 14 days. The APP/actin ratio was not significantly changed by PEG-RRK (Fig. 4A) suggesting that PEG-RRK had no effect on transgene expression over 14 days. In contrast, Abeta/Actin (Fig. 4B) and Abeta/APP (Fig. 4C) ratios were significantly lowered by PEG-RRK. This indicates a positive effect of PEG-RRK on Abeta clearance independent on its production by the transgene.

## Patent Claims

1. Method for the production of a lysine-PEGylated IGF-I or a IGF-I variant, said variant comprises one or two amino acid(s) selected from the group consisting of lysine 27, 65 and/or 68 is/are substituted independently by another polar amino acid, characterized in

   a) cultivating a prokaryotic host cell comprising an expression vector containing a nucleic acid encoding a fusion protein comprising said IGF-I or IGF-I variant N-terminally linked to the C-terminus of a propeptide,
   b) that said propeptide ends C-terminal with amino acids -Y-Pro, wherein Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro,
   c) recovering and PEGylating said fusion protein,
   d) cleaving said PEGylated fusion protein with IgA protease, and
   e) recovering said PEGylated IGF-I or IGF-I variant.

2. Method according to claim 1, characterized in that the propeptide is shown by the formula

   $$Met\text{-}X_1\text{-}His_n\text{-}X_2\text{-}Y\text{-}Pro\text{-},$$

   wherein
   - Met denotes methionine
   - $X_1$ is a bond, serine or asparagine
   - His is histidine,
   - n is a number from 0 to 10,
   - $X_2$ is a linker peptide, selected form the group, consisting of peptides SEQ ID NO: 6-10,
   - Pro is proline, and
   - Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro.

3. Method according to claims 1 to 2, characterized in that said propeptide do not comprise a lysine residue.

4. Method according to claims 1 to 3, characterized in that said polar amino acid(s) is/are independently arginine, glutamine or asparagine.

5. Method according to claims 1 to 4, characterized in that the lysine-PEGylated IGF-I variant is mono- or diPEGylated at lysine residue(s) 65 and 68.

6. Method according to claim 5, characterized in that the lysine-PEGylated IGF-I variant is RRK and said variant is monoPEGylated at lysine residue 68 or the lysine-PEGylated IGF-I variant is RKR and said variant is monoPEGylated at lysine residue 65.

7. Method according to claim 5, characterized in that the lysine-PEGylated IGF-I variant is RKK and said variant is mono- or diPEGylated at lysine residues 65 and 68.

8. Method according to claim 5, characterized in that the lysine-PEGylated IGF-I variant is a mixture of RRK, RKR or RKK and said variant is is mono- or diPEGylated at lysine residue(s) 65 and 68.

9. Method according to claims 1 to 4, characterized in that the lysine-PEGylated IGF-I is randomly mono- or diPEGylated.

10. Method according to claims 1 to 9, characterized in that said PEG has an overall molecular weight of from 20 to 100 kDa.

11. Method according to claims 1 to 10, characterized in that the poly(ethylene glycol) group(s) is/are branched poly(ethylene glycol) group(s).

12. Fusion protein comprising a lysine-PEGylated IGF-I or IGF-I variant said variant comprising one or two amino acid(s) selected from the group consisiting of lysine 27, 65 and/or 68 is/are substituted independently by another polar amino acid, N-terminally linked to the C-terminus of a propeptide, characterized in that said propeptide ends C-terminal with amino acids -Y-Pro, wherein Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro.

13. Fusion protein according to claim 12, characterized in that said propeptide has a length of up to 30 amino acids.

14. Fusion protein according to claim 12 or 13, characterized by the formula

$$Met\text{-}X_1\text{-}His_n\text{-}X_2\text{-}Y\text{-}Pro\text{-}[IGF\text{-}I \text{ or } IGF\text{-}I \text{ variant}],$$

wherein

- IGF-I denotes human IGF-I and IGF-I variant denotes IGF-I, wherein one or two amino acid(s) selected from the group consisiting of lysine 27, 65 and/or 68 is/are substituted independently by another polar amino acid,
- Met denotes methionine,
- $X_1$ is a bond, serine or asparagine ,
- His is histidine,
- n is a number from 0 to 10,
- $X_2$ is a linker peptide, selected form the group, consisting of peptides SEQ ID NO: 6-10,
- Pro is proline, and
- Y is selected from the group consisting of Pro, Pro-Ala, Pro-Gly, Pro-Thr, Ala-Pro, Gly-Pro, Thr-Pro, Arg-Pro, or Pro-Arg-Pro.

15. Lysine-PEGylated IGF-I, characterized in not comprising a N-terminal methionine.

16. Lysine-PEGylated IGF-I variant wherein one or two amino acid(s) selected from the group consisiting of lysine 27, 65 and/or 68 is/are substituted independently by another polar amino acid, characterized in that said variant do not comprise a N-terminal methionine.

17. Pharmaceutical composition comprising a lysine-PEGylated IGF-I or IGF-I variant according to claim 15 or 16.

18. Use of a lysine-PEGylated IGF-I or IGF-I variant according to claim 15 or 16 for the preparation of a medicament for the treatment of Alzheimer's disease (AD).

19. Method for the treatment of Alzheimer's disease (AD), characterized in that a pharmaceutically effective amount a lysine-PEGylated IGF-I or IGF-I variant according to claim 15 or 16 is administered to a patient in need of such treatment.