

Synthesis of cyclic imide containing peptide products

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Description

The present invention relates to a method of synthesizing a peptide product comprising at least one cyclic imide group. Further, the invention relates to a peptide product comprising at least one cyclic imide group, which is substantially free from degradation products. The peptide product may be used as a reference material for the quality control of pharmaceutical peptides, particularly for the quality control of GLP-1 agonists like exendin peptides.

Using well-known recombinant DNA and chemical solid phase synthesis processes, several proteins and peptides have been synthesized for pharmaceutical use. The production of these proteins and peptides, however, often leads to a multiplicity of undesired synthesis by-products. This is especially the case when they are produced by solid phase synthesis. With an increase in length of the peptide/protein, leading to an increase in the synthesis steps, these by-products may be present in 50 to 70% of the crude product.

The by-products may include peptide products containing cyclic imide groups, e.g. aspartimides or glutarimides. Such cyclic imide groups are generated during or after the solid phase synthesis, e.g. when removing a peptide from the solid phase carrier or when formulating or storing a peptide composition (Geiger & Clarke, J. Biol.Chem. 262 (1987), 785-794; Hekman et al., J Pharm. Biomed. Anal. 20 (1999), 763-772; Lindner & Helliger, Exp. Gerontol. 36 (2001), 1551-1563; Aswad et al., J. Pharm. Biomed. Anal. 21 (2000), 1129-1136; Ritz-Timme & Collins, Ageing Res. Rev.1 (2002), 43-59; Mergler et al., J. Pept. Sci.9 (2003), 36-46; Mergler et al., J. Pept. Sci. 9 (2003), 518-526; Mergler et al., J. Pept. Sci.11 (2005), 650-657; Cebrian et

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al., J. Pept. Res.62 (2003), 238-244; De Boni et al., J. Chrom. A. 1022 (2004), 95-102; and Houchin et al., J. Contr. Release 112 (2006), 111-119).

A targeted synthesis of peptide products containing cyclic imide groups is not known. In the past, aspartimides or glutarimides have been generated by "forced degradation" procedures, wherein a peptide comprising the amino acids Asp or Asn is subjected to degradation conditions, e.g. stirring at pH 4 or pH 8 for one to two days, optionally at an elevated temperature of about 40 to about 50°C. These methods, however, have the disadvantage that in addition to the desired products, numerous other degradation products are obtained. Particularly, the cyclic imide group may be subject to further reactions, e.g. racemisation, formation of an isoaspartate peptide, conversion from Asn to Asp, opening of the aspartimide by nucleophilic reagents, peptide bond cleavage, etc. Thus, after performing a forced degradation, it is often difficult to purify the desired cyclic imide product from a complex mixture of peptidic compounds.

In order to overcome these difficulties occurring in the manufacture and purification of the cyclic imide peptide products, the present inventors have developed a targeted synthesis for cyclic imide containing peptides.

This method is shown exemplarily for the peptide Lixisenatide (AVE0010), a GLP-1 agonist having a length of 44 amino acids long. The amino acid sequence of Lixisenatide is shown in SEQ ID NO:1:

H-G-E-G-T-F-T-S-D-L-S-K-Q-M-E-E-E-A-V-R-L-F-I-E-W-L-K-N-G-G-P-S-S-G-A-P-P-S-K-K-K-K-K-K-NH₂

Lixisenatide is produced by a chemical solid phase synthesis process.

Aspartimides may be formed from peptide sequences -Asn-X- or -Asp-X-, wherein X denotes a C-terminally adjacent amino acid residue. In the former case, the cyclisation involves removal of ammonia (NH₃) and in the latter

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case, removal of water (H_2O). In Figure 1, the formation of aspartimides in AVE0010, namely on position -Asn(28)-Gly(29)- and Asp(9)-Leu(10) is illustrated. The resulting products are designated [Asp(9)- H_2O]-AVE0010 and [Asn(28)- NH_3]-AVE0010, respectively. In principle, the same reaction results in the formation of glutarimides from the amino acids Gln or Glu.

The present inventors have now found that a targeted synthesis of cyclic imide groups is possible when using an amino acid building block with an unprotected $COOH$ or $CONH_2$ side chain, e.g. Asp, Asn or Glu, Gln in the coupling step during peptide synthesis at predetermined positions where formation of cyclic imide groups is desired. At other positions where formation of cyclic imide groups is not desired, amino acid building blocks with a protected $COOH$ or $CONH_2$ side chain may be used in the synthesis. By increasing the coupling time and repeated addition of coupling reagents, the cyclic imide groups may be obtained in nearly quantitative yield. Thus, the present invention allows selective formation of cyclic imide groups at predetermined positions of a peptide sequence without affecting other positions of the peptide sequence potentially susceptible to cyclic imide group formation.

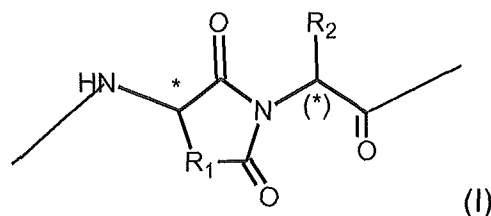
In Figure 2, formation of an aspartimide group is shown. An amino-protected (e.g. by Fmoc) protected Asp building block with an unprotected carboxy side chain is added to a carrier resin-bound peptide derivative with a free amino group in the presence of coupling reagents. Formation of the aspartimide group is favoured by increasing the coupling time to ≥ 1 day and repeated adding of coupling reagents. The other steps of peptide synthesis, i.e. previous and/or subsequent steps, may be carried out under standard conditions. It should be avoided, however, to use piperidine for the cleavage of the Fmoc protection group, because this may lead to an opening of the aspartimide ring.

The method of the present invention allows a targeted synthesis of cyclic imide peptide products in high yield and purity. These peptide products may

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e.g. be used as reference materials for the quality control of pharmaceutical peptide products such as lixisenatide.

A subject-matter of the present invention is a method of synthesizing a peptide product comprising at least one cyclic imide group of formula (I) or a salt or solvate thereof:



wherein

R₁ is a bridge (or biradical) of one or two atoms lengths,

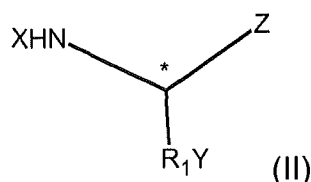
R₂ is an amino acid side chain,

* denotes an asymmetric C atom, preferably in the L-configuration, and

(*) denotes an optionally asymmetric C atom, preferably in the L-configuration,

comprising the steps:

(a) coupling a synthesis building block of formula (II):



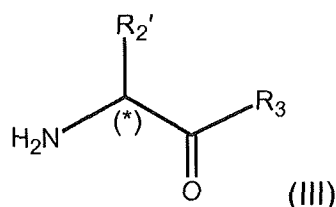
wherein

X is an amino protecting group,

Y is an unprotected carboxy or carboxamido group,

Z is a carboxy group, and

* denotes an asymmetric C atom, preferably in the L-configuration, to a peptide product of formula (III)



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wherein

R_2 is an optionally protected amino acid side chain,

R_3 is a peptidic residue, preferably bound to a solid phase carrier, and

(*) denotes an optionally asymmetric C atom, preferably in the L-configuration,

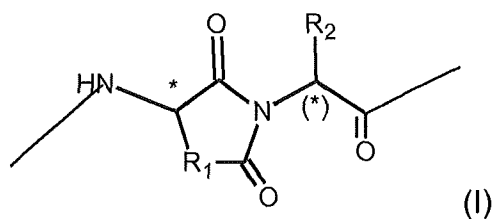
under conditions wherein the cyclic imide group of formula (I) is formed,

(b) cleaving off the amino protecting group X,

(c) optionally continuing the peptide synthesis, and

(d) optionally purifying the peptide product (I).

A further subject-matter of the present invention is a peptide product comprising at least one cyclic imide group of formula (I) or a salt or solvate thereof:



wherein

R_1 is a bridge (or biradical) of one or two atoms lengths,

R_2 is an amino acid side chain,

* denotes an asymmetric C atom, and

(*) denotes an optionally asymmetric C atom.

Particularly the peptide product is a GLP-1 agonist such as an exendin peptide, more particularly lixisenatide (AVE0010).

A further subject-matter of the present invention is the use of a peptide product of formula (I) or a salt or solvate thereof as described above as a reference material for the quality control of pharmaceutical peptides, particularly of GLP-1 agonist peptides such as exendin peptides, e.g. lixisenatide.

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Still, a further subject-matter of the invention is a reagent kit for determining the amount of impurities in a lixisenatide (AVE0010) product composition comprising:

- 5 (i) at least one stock preparation of [Asp(9)-H₂O]-AVE0010 and/or
- (ii) at least one stock preparation of [Asn(28)-NH₃]-AVE0010.

10 Still, a further subject-matter of the present invention is a method for the quality control of a composition comprising a pharmaceutical peptide product, particularly a GLP-1 agonist peptide product, e.g. an exendin peptide product, more particularly a lixisenatide (AVE0010) product, comprising quantitatively determining the amount of a peptide product with a cyclic imide group of formula (I) or a salt or solvate thereof in said composition.

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The present invention relates to a method of synthesizing a peptide product. The term "*peptide product*" encompasses peptides and proteins having a length of at least 5 or at least 10 amino acids and up to 50 or up to 100 amino acids or even longer. The peptide product may consist of genetically encoded amino acid building blocks or may comprise non-genetically encoded amino acid building blocks, e.g. non-naturally occurring amino acids, D-amino acids or chemically modified amino acids or may consist of several peptide chains linked e.g. by disulfide bridges. The peptide product may further contain modifications at the N-and/or C-terminus and/or at side chains, e.g. an acylation, an amidation or the addition of non-peptide side chain groups such as lipophilic groups. The peptide product may be linear or circular. Preferably, the peptide product has a length from 5-100 amino acids.

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The peptide product of the invention may be in the form of a salt, e.g. a pharmaceutically acceptable salt or solvate, e.g. a hydrate. Examples of pharmaceutically acceptable salts are described in Remington: The Science and Practice of Pharmacy, (20th ed.) ed. A.R. Gennaro A.R., 2000, Lippencott

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Williams & Wilkins or in Handbook of Pharmaceutical Salts, Properties, Selection and Use, e.d. P.H. Stahl, C.G. Wermuth, 2002, jointly published by Verlag Helvetica Chimica Acta, Zurich, Switzerland, and Wiley-VCH, Weinheim, Germany. Preferably, the salt is a trifluoroacetate or acetate salt.

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The peptide product comprises at least one amino acid residue capable of forming a cyclic imide group of formula (I), particularly an amino acid residue having a side chain with a carboxy or carboxamide group such as Asp, Asn, Glu or Gln, located N-terminally to an amino acid residue with an N-atom in the peptide chain accessible for cyclisation. The C-terminally located amino acid residue may e.g. be selected from Gly, Leu, His, Asp, Arg, Phe, Ala, Cys, Gln, Glu, Lys, Met, Asn, Ser, Tyr, Thr, Ile, Trp in their D- or L-configuration and unnatural (e.g. non-genetically encoded) amino acids, which are e.g. listed in supplier's catalogues.

15

Preferably, the peptide product which has been synthesized according to the present invention comprises at least one cyclic imide group of formula (I) and at least one amino acid residue having a side chain with a carboxy or carboxamide group such as Asp, Asn, Glu or Gln, which is not present as cyclic imide group.

20

The synthesis of the peptide product is carried out by chemical synthesis procedures, particularly by a solid phase synthesis procedure which is well-known in the art, e.g. a procedure involving a stepwise coupling of synthesis building blocks to a peptide chain bound to a carrier, e.g. a synthetic resin. In a preferred embodiment of the invention, the peptide product is a GLP-1 agonist peptide, such as an exendin peptide, e.g. exendin-4, liraglutide or lixisenatide (AVE0010) or GLP-1 receptor agonist like GLP-1 or -2, oxyntomodulin, glucagon or peptides which bind and activate both the glucagon and the GLP-1 receptor (Hjort et al., Journal of Biological Chemistry, 269, 30121-30124, 1994; Day JW et al., Nature Chem. Biol. 5:749-757, 2009) and suppress body weight gain and reduce food intake which are described in patent applications WO 2008/071972, WO

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2008/101017, WO 2009/155258, WO 2010/096052, WO 2010/096142, WO
2011/075393, WO 2008/152403, WO 2010/070251, WO 2010/070252, WO
2010/070253, WO 2010/070255, WO 2011/160630, WO 2011/006497, WO
2011/152181, WO 2011/152182, WO 2011/117415, WO 2011/117416, the
5 contents of which are herein incorporated by reference, or GIP and peptides
which bind and activate both the GIP and the GLP-1 receptor and optionally
the glucagon receptor, and improve glycemic control, suppress body weight
gain and reduce food intake as described in patent applications WO
2011/119657, WO 2012/138941, WO 2010/011439, WO 2010/148089, WO
10 2011/094337, and WO 2012/088116, the contents of which are herein
incorporated by reference. Further examples of peptide products are insulins
and insulin analogues or DPP-4 inhibitors. More preferably, the peptide
product is an exendin peptide, most preferably lixisenatide (AVE0010).

15 Step (a) of the method of the invention comprises coupling a synthesis acid
building block of formula (II) to a peptide product of formula (III). The
building block (II) comprises a group Z, wherein Z is a carboxy group
capable of coupling to an amino group under coupling conditions, i.e. in the
presence of coupling reagents in an organic solvent. Further, the amino acid
20 building block (II) comprises a side chain R_1Y , wherein R_1 is a biradical or
bridge having a length of one to two atoms, preferably a C_1 - C_2 group, more
preferably a $-CH_2-$ or a $-CH_2-CH_2-$ group. Y is an unprotected carboxy or
carboxamido group. Building block (II) also has a protected amino group
 NHX , wherein X is an amino protecting group, e.g. a
25 fluorenylmethoxycarbonyl (Fmoc) group or another base-labile protecting
group or an acid-labile protecting group such as butoxycarbonyl (Boc), trityl
(Trt) or a protecting group selected from carboxybenzyl (Cbz),
allyloxycarbonyl (Alloc) or another protecting group for amino groups
mentioned in Green's Protective Groups in Organic Synthesis, John Wiley &
30 Sons, 4th ed. 2006, chapter 7, Protection for the Amino Group, mentioned in
Protecting Groups, P.J. Kocierski, Thieme, 3rd ed. 2005, chapter 8, Amino
Protecting Groups or mentioned in Houben-Weyl, Methods in Organic
Chemistry, Synthesis of Peptides and Peptidomimetics, 4th ed. 2001, chapter

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2, Protection of Functional groups, the contents of which are herein incorporated by references. Building block (II) further has an asymmetric carbon atom denoted by *. Preferably, the asymmetric carbon atom is in the L-configuration.

5

Peptide product (III), which may be an intermediate product of peptide synthesis, has a free amino group capable of reacting with group Z of synthesis building block (II) under coupling conditions, i.e. in the presence of coupling reagents in an organic solvent. The intermediate peptide product
10 comprises an N-terminal amino acid building block with an optionally protected amino acid side chain R_2 and a peptidic residue R_3 constituted of one or more amino acids. The peptidic residue is preferably bound to a solid phase carrier, e.g. a resin suitable for peptide synthesis. Peptide product (III) may also contain an asymmetric carbon atom denoted as (*) when R_2 is
15 different from H. Preferably, the asymmetric carbon atom is in the L-configuration.

The coupling conditions in step (a) preferably comprise a reaction time of at least 4 h, 8 h, 12 h, 16 h or 24 h and up to 48 h, 72 h or 96 h. Further, the
20 coupling conditions preferably comprise a reaction temperature between 0 and 50°C, preferably between 15 and 40°C. The coupling reaction is carried out in the presence of a coupling reagent such as TBTU (O-(benzotriazol-1-yl)-N,N,N',N'-tetramethyluronium tetrafluoroborate, HBTU (2-(1H-benzotriazole-1-yl),1,1,3,3-tetramethyluronium) hexafluorophosphate or
25 HOBt (1-hydroxybenzotriazole)/DIC (diisopropylcarbodiimide) and an organic base such as DIPEA (diisopropylethylamine) in a suitable organic solvent such as DMF (dimethylformamide), or other coupling reagents. For example, coupling reagents named in A. El-Faham, F. Albericio, Chem. Rev. 2011, 111, 6557-6602, can be employed, the content of which is herein
30 incorporated.

Preferably, the coupling step is carried out under conditions wherein the yield of the cyclic imide product is $\geq 50\%$, $\geq 60\%$, $\geq 70\%$, $\geq 80\%$ or $\geq 90\%$

based on the amount of the total yield in coupling step (a), i.e. the amount of amino acid building block (II) coupled to the peptide intermediate product (III).

5 Step (b) of the inventive method comprises cleaving off the amino protecting group X after the coupling step in the presence of a deprotecting agent such as DBU (1,8-diazabicyclo[5.4.0]undec-7-ene). Further suitable deprotecting agents are mentioned in Green's Protective Groups in Organic Synthesis, John Wiley & Sons, 4th ed. 2006, chapter 7, Protection for the Amino Group, 10 mentioned in Protecting Groups, P.J. Kocierski, Thieme, 3rd ed. 2005, chapter 8, Amino Protecting Groups or mentioned in Houben-Weyl, Methods in Organic Chemistry, Synthesis of Peptides and Peptidomimetics, 4th ed. 2001, chapter 2, Protection of Functional groups, the contents of which are herein incorporated by references. The use of piperidine as a deprotecting 15 agent is less recommended since it results in a ring opening of the cyclic imide group.

Optional Step (c) comprises continuing the synthesis of the peptide product after formation of the cyclic imide group. The synthesis may be continued 20 under standard conditions except that the use of piperidine, as a deprotecting reagent should be avoided. Step (c) may also comprise deprotecting side chain protected amino acid groups and cleaving the peptide off from the solid phase carrier. These procedures may be carried out under standard conditions as known in the art.

25 Optional step (d) comprises purifying the peptide product (I) from other peptides obtained in the peptide synthesis procedure. Preferably, the purification involves a chromatographic procedure. The term "*chromatographic procedure*" involves a chromatographic procedure suitably 30 for the purification of peptide products, including e.g. ion exchange chromatography, hydrophobic interaction chromatography, affinity chromatography, size exclusion chromatography, and particularly high performance liquid chromatography (HPLC) and more particularly Reverse

Phase HPLC, or combinations of several procedures. More preferably, the chromatographic procedure involves at least one Reverse Phase HPLC chromatography step .

5 As a result of the inventive synthesis method, an isolated and purified peptide product comprising a cyclic imide group of formula (I) may be obtained. Preferably, this peptide product is substantially free from degradation products, e.g. deamidation products, racemised products and/or isoasparagine-containing products. Preferably, the amount of degradation
10 products is less than 1%, 0.5% or 0.1% based on the amount of the total product as measured by means of chromatography, e.g. HPLC.

The peptide product comprises at least one cyclic imide group, e.g. 1, 2 or 3 cyclic imide groups. Preferably, the peptide product comprises one or two
15 cyclic imide groups. More preferably, the peptide product comprises one or more uncyclized cyclic imide groups.

The peptide product is preferably a therapeutic peptide, e.g. an exendin peptide, particularly lixisenatide (AVE0010) having at least one cyclic imide
20 group. Specific examples of preferred peptide products are [Asp(9)-H₂O]-AVE0010, [Asn(28)-NH₃]-AVE0010, [Asp(9)-H₂O]-Exendin-4, [Asn(28)-NH₃]-Exendin-4, [Asp(9)-H₂O]-Liraglutide, [Asp(16)-H₂O]-GLP-1(7-36), [Asp(9)-H₂O]-Glucagon, [Asp(15)-H₂O]-Glucagon, [Asp(21)-H₂O]-Glucagon, [Asn(28)-NH₃]-Glucagon, [Asp(9)-H₂O]-Oxyntomodulin, [Asp(15)-H₂O]-
25 Oxyntomodulin, [Asp(21)-H₂O]-Oxyntomodulin, [Asn(28)-NH₃]-Oxyntomodulin, [Asn(32)-NH₃]-Oxyntomodulin, [Asn(34)-NH₃]-Oxyntomodulin, [Asn(35)-NH₃]-Oxyntomodulin and all peptides with the motif -Asn-X- and -Asp-X- which bind and activate both the glucagon and the GLP-1 receptor (Hjort et al., Journal of Biological Chemistry, 269, 30121-
30 30124, 1994; Day JW et al., Nature Chem Biol, 5:749-757, 2009) and suppress body weight gain and reduce food intake which are described in patent applications WO 2008/071972, WO 2008/101017, WO 2009/155258, WO 2010/096052, WO 2010/096142, WO 2011/075393, WO 2008/152403,

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WO 2010/070251, WO 2010/070252, WO 2010/070253, WO 2010/070255,
WO 2011/160630, WO 2011/006497, WO 2011/152181, WO 2011/152182,
WO 2011/117415, WO 2011/117416, the contents of which are herein
incorporated by reference, or GIP and peptides which bind and activate both
5 the GIP and the GLP-1 receptor and optionally the glucagon receptor, and
improve glycemic control, suppress body weight gain and reduce food intake
as described in patent applications WO 2011/119657, WO 2012/138941,
WO 2010/011439, WO 2010/148089, WO 2011/094337, and WO
2012/088116, the contents of which are herein incorporated by reference.

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The peptide product of the invention may be used as a reference material,
e.g. for the quality control of pharmaceutical peptides, particularly for use in
a quality control method wherein the amount of undesired cyclic imide group
containing by-products in a peptide product preparation is quantitatively
15 determined.

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Quantitative determination of by-products in a peptide product sample
preferably involves mass spectrometry. In addition to mass spectrometry, the
determination may involve a prior chromatographic procedure, e.g. in order
20 to separate other impurities from the peptide product or from other
ingredients of the composition. Preferably, mass spectrometry is combined
with HPLC.

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Mass spectrometry is based on a measurement of the mass-to-charge ratio
25 of charged particles. In a typical mass spectrometry procedure, the sample is
loaded onto the mass spectrometry instrument and volatilized. The sample
components are ionized and the resulting ions are separated in the mass
analyzer by electromagnetic fields. The resulting ions are detected and the
signal is processed into a mass spectrum. For the ionization of peptide
30 products, electrospray ionization (ESI) and matrix-assisted laser desorption/
ionization (MALDI) may be used. The resulting ions may be detected by
highly sensitive methods such as Orbitrap or Fourier Transform (FT)-Ion
Cyclotron Resonance (ICR) detection systems.

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By means of mass spectrometry, a peak derived from a cyclic imide group containing by-product may be identified, which differs from the mass of the non-cyclisized product by 18 (mass of H₂O) or 17 (mass of NH₃).

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Further, the present invention shall be explained in more detail by the following examples describing synthesis, chromatographic purification and analytic characterization of the cyclic imide group containing peptide [Asp(9)-H₂O]-AVE0010.

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Examples

1. Synthesis of [Asp(9)-H₂O]-AVE0010

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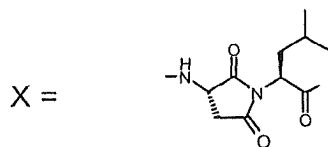
[Asp(9)-H₂O]-AVE0010 is a by-product in the synthesis of the pharmaceutical peptide product AVE0010. It is generated when the side chain of amino acid Asp(9) forms an aspartimide with the N-atom of the adjacent amino acid Leu(10) under removal of water.

20

The amino acid sequence of [Asp(9)-H₂O]-AVE0010 is as follows:

H-His-Gly-Glu-Gly-Thr-Phe-Thr-Ser-**X**-Ser-Lys-Gln-Met-Glu-Glu-Glu-Ala-Val-Arg-Leu-Phe-Ile-Glu-Trp-Leu-Lys-Asn-Gly-Gly-Pro-Ser-Ser-Gly-Ala-Pro-Pro-Ser-Lys-Lys-Lys-Lys-Lys-Lys-NH₂

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Peptide synthesis was carried out with the peptide synthesizer Bio536 (CS Bio). As a starting material, N-terminally Fmoc protected (20-44)-AVE0010 resin was used. The starting material was prepared by peptide synthesis under standard conditions.

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25.56 g Fmoc-(20-44)-AVE0010 resin were mixed with 250 ml DMF, stirred for 5 minutes and then swollen for 2 hours. DMF was then aspirated through a frit. After the swelling, Fmoc cleavage was carried out with 25 % piperidine in DMF.

Then, amino acids Val(19) to Leu(10) were coupled to the starting material under standard conditions using amino acid derivatives with a Fmoc protected amino group and a protected side chain, e.g. an O-t-butyl (OtBu) protected Glu side chain, a trityl(Trt)-protected Gln side chain, a butyloxycarbonyl(Boc)-protected Lys side chain and a t-butyl(tBu)-protected Ser side chain.

Then, a Fmoc-Asp-OH building block (without side chain protection group) was coupled under conditions favouring the formation of an aspartimide group.

4.26 g Fmoc-Asp-OH, 1.9 g HOBT hydrate and 2 mL DIC in 250 mL DMF were mixed with the resin. The reaction mixture was stirred overnight. The coupling solution was then pumped out and the resin was washed twice with DMF. Then, 3 eq HOBT and 3 eq DIC in DMF were mixed with the resin. The resin was stirred over the weekend.

To determine the degree of aspartimide formation, a resin sample was treated with a cleavage mixture called King's Cocktail (D.S. King, C.G. Fields, G.B. Fields, Int. J. Peptide Protein Res. 36, 1990, 255-266) to liberate the aspartimide containing peptide from the resin. By means of mass-spectrometric measurements, it was found that the coupling product was mainly present in form of a cyclic aspartimide.

Subsequently, a solution of 2% of DBU in DMF was used for the Fmoc cleavage.

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Finally, amino acids Ser(8) to Gly(1) were coupled under standard conditions except that the Fmoc protection group was not cleaved with piperidine but with DBU, in order to prevent an opening of the cyclic aspartimide group. As a result, 30.5 g [Asp(9)-H₂O]-AVE0010 on resin were obtained.

5

The cleavage of peptide from resin and the side chain protection group was carried out with King's Cocktail. 9.25 g raw product (purity of 23.4% as measured by UV at 215 nm) resulted from 30.5 g Fmoc protected resin after the solid phase synthesis.

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The cleavage of the peptide from the resin was carried out under standard conditions (King et al., 1990, Supra). In total, 9.25 g of crude [Asp(9)-H₂O]-AVE0010 were obtained after drying under vacuum.

15 2. Chromatographic purification of [Asp(9)-H₂O]-AVE0010

Purification was carried out by two RP-HPLC steps and subsequent freeze drying. The RP-HPLC steps were conducted with a Varian PrepStar device. Stainless steel columns packed with C18 reverse phase material (e.g. Daisogel C18 for the first step or Hydrospher C18 for the second step) were used as stationary phase. H₂O + 0.1% trifluoroacetic acid were used as mobile phase A and acetonitrile as mobile phase B. The gradient was carried out at 0-80% mobile phase B (Daisogel) and 0-35% mobile phase B (Hydrospher), respectively.

25

As a result, 540 mg [Asp(9)-H₂O]-AVE0010 with a purity of 91.50 % (area % as measured by HPLC) were obtained. An analytical chromatogram of the purified product is shown in Figure 3.

30 3. Analytic characterization

The purified product was characterized mass spectrometrically. Purified AVE0010 was used as a reference standard.

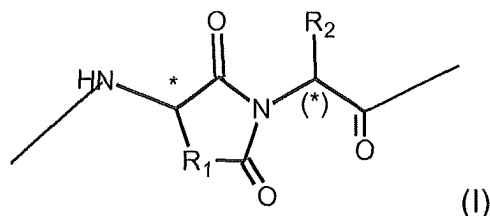
- 16 -

This analytic characterization showed the correct product [Asp(9)-H₂O]-AVE0010 with a molecular weight $(M+H)^+ = 4838.460$, and the AVE0010 standard of 4856.544. The mass difference of [Asp(9)-H₂O]-AVE0010 to
5 AVE0010 is 18.084 which equals to an H₂O molecule. The theoretical monoisotopic molecular weight of [Asp(9)-H₂O]-AVE0010 is 4837.534.

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Claims

1. A method of synthesizing a peptide product comprising at least one cyclic imide group of formula (I) or a salt or solvate thereof:



wherein

R_1 is a bridge of one or two atoms lengths,

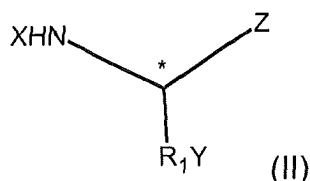
R_2 is an amino acid side chain,

10 * denotes an asymmetric C atom, and

(*) denotes an optionally asymmetric C atom,

comprising the steps:

(a) coupling a synthesis building block of formula (II):



wherein

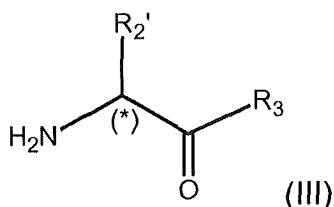
X is a base-labile amino protecting group,

Y is an unprotected carboxy or carboxamido group,

* denotes an asymmetric C atom, and

Z is a carboxy group,

20 to a peptide product of formula (III)



wherein

R_2' is an optionally protected amino acid side chain,

R_3 is a peptidic residue, and

(*) denotes an optionally asymmetric C atom

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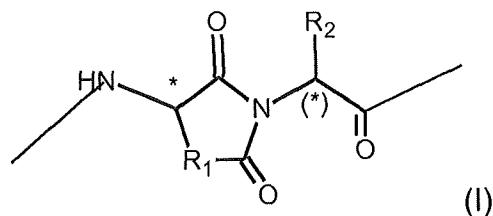
- under conditions wherein the cyclic imide group of formula (I) is formed,
- (b) cleaving off the amino protecting group X,
 - (c) optionally continuing the peptide synthesis, and
 - (d) optionally purifying the peptide product (I).

5

- 2. The method of claim 1, wherein R₁ is -CH₂-.
- 3. The method of claim 1, wherein R₁ is -CH₂-CH₂-.
- 10 4. The method of any one of claims 1-3, wherein Y is a carboxy group.
- 5. The method of any one of claims 1-4, wherein Y is a carboxamido group.
- 15 6. The method of any one of claims 1-5, wherein X is an Fmoc amino protecting group
- 7. The method of any one of claims 1-6, wherein coupling step (a) is carried out on resin.
- 20 8. The method of any one of claims 1-7, wherein the coupling conditions in step (a) comprise a reaction time of at least 12 h, a temperature of between 15 and 40°C, and optionally repeated addition of coupling reagents such as TBTU or HBTU with DIPEA or HOBt/DIC.
- 25 9. The method of any one of claims 1-8, wherein the coupling conditions in step (a) comprise dimethylformamide (DMF) as organic solvent.
- 30 10. The method of any one of claims 1-9, wherein the yield of a cyclic imide product in coupling step (a) is $\geq 50\%$, $\geq 60\%$, $\geq 70\%$, $\geq 80\%$ or $\geq 90\%$ based on the amount of the total yield of a coupling product in step (a).

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11. The method of any one of claims 1-10 , wherein cleaving step (b) is carried out with a deprotecting agent selected from 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU).
- 5 12. The method of any one of claims 1-11 , wherein the cyclic imide group of formula (I) is selectively introduced at at least one predetermined position of the peptide product.
13. A peptide product comprising at least one cyclic imide group of formula (I) or a salt or solvate thereof:
- 10



wherein

- R_1 is a biradical of one or two atoms lengths,
- 15 R_2 is an amino acid side chain,
- * denotes an asymmetric C atom, and
- (*) denotes an optionally asymmetric C atom,
- which is an exendin peptide, particularly *lixisenatide* (AVE0010) having at least one cyclic imide group and wherein said cyclic imide group is
- 20 present at position Asp(9).
14. The peptide product of claim 13 which is selected from [Asp(9)-H₂O]-AVE0010, [Asp(9)-H₂O]-Exendin-4, and [Asp(9)-H₂O]-Liraglutide.
- 25 15. The use of a peptide product of any one of claim 13 or 14 as a reference material for the quality control of pharmaceutical peptide products.
16. A reagent kit for determining the amount of impurities in a *lixisenatide* (AVE0010) product composition comprising:
- 30

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- (i) at least one stock preparation of [Asp(9)-H₂O]-AVE0010 and/or
- (ii) at least one stock preparation of [Asn(28)-NH₃]-AVE0010.

17. A method for the quality control of a composition comprising a
s pharmaceutical exendin peptide product, more particularly a
lixisenatide (AVE0010) product, comprising quantitatively determining
the amount of a peptide product with a cyclic imide group of formula (I)
or a salt or solvate thereof in said composition.