

5

METHOD FOR NATIVE LIGATION OF POLYPEPTIDES

FIELD OF THE INVENTION

10 The present invention relates to a method for native ligation of polypeptides. The invention also relates to functionalized polypeptides useful for implementing this method for native ligation, as well as a method for manufacturing these functionalized polypeptides. The invention also relates to an amine compound as well as a functionalized resin, useful for
15 implementing the method for manufacturing functionalized polypeptides.

TECHNICAL BACKGROUND

 The synthesis of polypeptides by conventional solid-phase methods, amino acid by amino acid, is limited by low yields when the polypeptides
20 synthesized are of large size. For overcoming this limitation, assembly of two polypeptides by chemical ligation, in order to produce a longer polypeptide, is known.

 In general, it is desirable for the bond between the polypeptides assembled by ligation to be native, i.e. to correspond to the natural structure
25 of the polypeptides.

 Currently the main method for native ligation is that of Kent and Dawson, which is described for example in documents WO 96/34878 and WO 98/28434. This method is based on a chemoselective reaction between a (C-terminal) thioester peptide and a cysteinyl peptide. The main drawback
30 of this method is that manufacture of the thioester peptides requires complex chemical processes.

 An alternative method is so-called Staudinger ligation, described in documents WO 01/68565 and WO 01/87920. This comprises reaction of a phosphinothioester with an azide and hydrolysis of the combined reagents to
35 form an amide bond. This method is difficult to apply on an industrial scale.

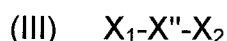
 A third method, described in document WO 2007/037812, is based on reaction of an α -keto acid with an amine in a reaction of decarboxylative condensation. However, the keto acids are molecules that are difficult to

manufacture and to incorporate in peptides. Moreover, this third method is difficult to apply in peptide synthesis laboratories that are not equipped with means for carrying out complex organic syntheses.

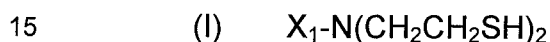
There is therefore a real need to develop a new method for native
 5 ligation of polypeptides, which is both effective and simpler to implement, including on an industrial scale.

SUMMARY OF THE INVENTION

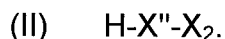
The invention relates firstly to a method for manufacturing a
 10 polypeptide of formula:



X_1 and X_2 each representing a peptide fragment, and X'' representing an amino acid residue comprising a thiol function, said method comprising at least one step of ligation reaction between a polypeptide of formula:



and a polypeptide of formula:



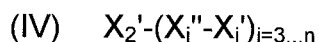
According to an embodiment, the ligation reaction is carried out by bringing a polypeptide of formula:

20

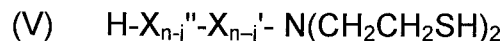


into contact with the polypeptide of formula (II), in the presence of at least one compound that reduces the disulphide bonds.

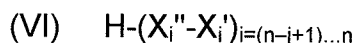
25 According to an embodiment, X_2 represents a peptide fragment of formula



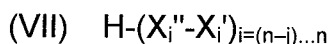
n being an integer greater than or equal to 3, each X_i'' , for i an integer comprised between 3 and n , representing an amino acid residue comprising a thiol function, and each X_i' , for i an integer comprised between 2 and n , representing a peptide fragment; the method comprising, before the step of ligation reaction between the polypeptide of formula (I) and the polypeptide of formula (II), a succession of $n-2$ steps of ligation reaction, the j -th step of ligation reaction, for j an integer comprised between 1 and $n-2$, being a
 30 ligation reaction between a polypeptide of formula:



in which the amine function and/or the thiol function of residue X_{n-j}'' is protected, and a polypeptide of formula:

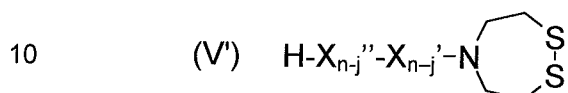


to form a polypeptide of formula:

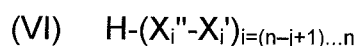


the polypeptide of formula (VII) undergoing deprotection of the thiol
 5 function of the residue X_{n-j}'' at the end of the ligation reaction.

According to an embodiment, one or more of the $n-2$ steps of ligation reaction between the polypeptide of formula (V) and the polypeptide of formula (VI) is carried out by bringing a polypeptide of formula:

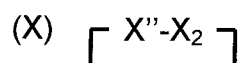


into contact with the polypeptide of formula:

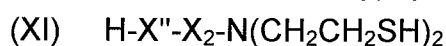


j being an integer comprised between 1 and $n-2$, in the presence of at
 15 least one compound that reduces the disulphide bonds.

The invention also relates to a method for manufacturing a cyclic polypeptide of formula:

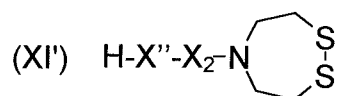


X_2 representing a peptide fragment, and X'' representing an amino acid residue comprising a thiol function, said method comprising at least one
 20 step of ligation reaction of a polypeptide of formula:



with itself.

25 According to an embodiment, the ligation reaction is carried out by bringing a polypeptide of formula:



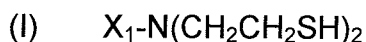
30 into contact with at least one compound that reduces the disulphide bonds.

According to an embodiment of any one of the preceding methods, the ligation reaction or ligation reactions are carried out in an aqueous medium, preferably at a pH comprised between 6.5 and 8.5, more particularly
 35 preferably between 7 and 8, and ideally of approximately 7.5.

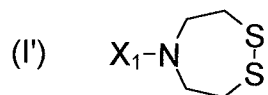
According to an embodiment of any one of the preceding methods, the ligation reaction or ligation reactions are carried out in the presence of at least one compound that reduces the disulphide bonds, selected from tris(2-

carboxyethyl)phosphine, 4-mercaptophenylacetic acid, dithiothreitol, benzyl mercaptan and mixtures thereof.

The invention further relates to a polypeptide of formula:



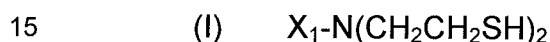
5 or of formula:



in which X_1 represents a peptide fragment.

10 According to an embodiment, X_1 comprises between 2 and 300 amino acid residues, preferably between 5 and 100 amino acid residues, more particularly preferably between 8 and 50 amino acid residues.

The invention also relates to a method for manufacturing a polypeptide of formula:



X_1 representing a peptide fragment, comprising at least one step of peptide synthesis and one step of C-terminal functionalization.

According to an embodiment, the step of peptide synthesis precedes the step of functionalization; the step of peptide synthesis supplies a
20 polypeptide of formula:



preferably comprising protective groups on its amine and carboxylic functions, with the exception of its C-terminal carboxylic function; and the step of functionalization comprises:

25 – reaction of the polypeptide of formula (IX) with the amine compound of formula:



in which G_1 represents a protective group, said protective group preferably forming a thioether, thioester or disulphide function, and
30 more particularly preferably being the triphenylmethyl group, in the liquid phase, to form the polypeptide of formula (I);

– optionally deprotection of the polypeptide of formula (I).

A subject of the invention is also a polymer resin support for solid-phase synthesis of polypeptides, comprising a main skeleton and NH-
35 $(CH_2CH_2-S-Trt-)_2$ functional groups or $NH-(CH_2CH_2-S-Trt-CO-NH-)_2$ functional groups, where Trt represents a triphenylmethyl group optionally substituted with one or more substituents, in particular selected from the substituents chlorine, methoxy, methyl, fluorine and cyano; in which the NH-

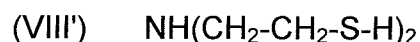
$(\text{CH}_2\text{CH}_2\text{-S-Trt-})_2$ functional groups are bound to the main skeleton by the two triphenylmethyl groups, or the $\text{NH}(\text{CH}_2\text{CH}_2\text{-S-Trt-CO-NH-})_2$ functional groups are bound to the main skeleton by the two amine groups.

A subject of the invention is also a polymer resin support for solid-phase synthesis of polypeptides, comprising a main skeleton and $\text{G}_2\text{-AA-N-}(\text{CH}_2\text{CH}_2\text{-S-Trt-})_2$ functional groups or $\text{G}_2\text{-AA-N-}(\text{CH}_2\text{CH}_2\text{-S-Trt-CO-NH-})_2$ functional groups, where Trt represents a triphenylmethyl group optionally substituted with one or more substituents, in particular selected from the substituents chlorine, methoxy, methyl, fluorine and cyano; AA represents an amino acid residue optionally bearing one or more protective groups; G_2 represents a hydrogen atom or a protective group of amine function; in which the $\text{G}_2\text{-AA-N-}(\text{CH}_2\text{CH}_2\text{-S-Trt-})_2$ functional groups are bound to the main skeleton by the two triphenylmethyl groups or the $\text{G}_2\text{-AA-N-}(\text{CH}_2\text{CH}_2\text{-S-Trt-CO-NH-})_2$ functional groups are bound to the main skeleton by the two amine groups.

According to an embodiment of the aforementioned polymer resin supports, the main skeleton is selected from the polystyrene, polyacrylamide, polyethylene glycol, cellulose, polyethylene, polyester, latex, polyamide, polydimethylacrylamide, polyethylene glycol-polystyrene copolymer, polyethylene glycol-polyacrylamide copolymer skeletons and derivatives thereof.

A subject of the invention is also a method for manufacturing a polymer resin support for solid-phase synthesis of polypeptides, comprising:

- supplying a polymer resin;
- functionalization of the polymer resin by reaction with the amine compound of formula:



According to an embodiment of the method for manufacturing the polymer resin support, the method comprises, prior to the step of functionalization of the polymer resin:

- supplying an amine compound of formula:

$$\text{(VIII)} \quad \text{NH}(\text{CH}_2\text{-CH}_2\text{-S-G}_1)_2$$

in which G_1 represents a protective group, said protective group preferably forming a thioether, thioester or disulphide function, and more particularly preferably being the triphenylmethyl group;
- deprotection of this amine compound to obtain the amine compound of formula (VIII').

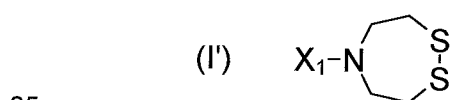
According to an embodiment of the method for manufacturing the polypeptide of formula (I):

- the step of functionalization precedes the step of peptide synthesis;
- 5 – the step of functionalization comprises:
 - coupling an amino acid to a polymer resin support comprising a main skeleton and $\text{NH}-(\text{CH}_2\text{CH}_2-\text{S-Trt-})_2$ functional groups or $\text{NH}-(\text{CH}_2\text{CH}_2-\text{S-Trt-CO-NH-})_2$ functional groups, as described above, to supply a primer support; or
 - 10 ▪ supplying a primer support, which is a polymer resin support comprising a main skeleton and $\text{G}_2\text{-AA-N}-(\text{CH}_2\text{CH}_2-\text{S-Trt-})_2$ functional groups or $\text{G}_2\text{-AA-N}-(\text{CH}_2\text{CH}_2-\text{S-Trt-CO-NH-})_2$ functional groups, as described above;
- the step of peptide synthesis comprises a succession of couplings of amino acids on the primer support.
- 15

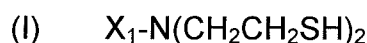
According to an embodiment of this method, the coupling of an amino acid to the polymer resin support comprises bringing the polymer resin support into contact with an amino acid halide or with an amino acid and an activating agent, preferably selected from PyBOP, BOP, PyBROP, more particularly preferably PyBROP.

- 20

The invention also relates to a method for manufacturing a polypeptide of formula:



in which X_1 represents a peptide fragment, comprising a step of oxidation of a polypeptide of formula:



preferably in contact with air, or in the presence of I_2 or of diamide, and in a buffer, said oxidation step preferably being preceded by a step of manufacture of the polypeptide of formula (I) according to the method described above.

- 30

According to an embodiment of the method for manufacturing a polypeptide of formula (III) or (X), the latter comprises a step of manufacture of the polypeptide of formula (I) and/or (V) or (XI) which is according to the method for manufacturing the polypeptide of formula (I) described above, or a step of manufacture of the polypeptide of formula (I') and/or (V') or (XI')

- 35

according to the method for manufacturing the polypeptide of formula (I') described above.

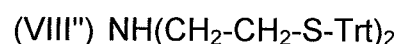
The invention also relates to a method for manufacturing a pharmaceutical composition comprising:

- 5 – manufacturing a polypeptide according to the method for manufacturing a polypeptide of formula (III) or (X) described above, and
- formulating this polypeptide with one or more pharmaceutically acceptable adjuvants.

10 The invention also relates to a method for manufacturing a diagnostic device comprising:

- manufacturing a polypeptide according to the method for manufacturing a polypeptide of formula (III) or (X) described above, and
- 15 – formulating this polypeptide in a form suitable for diagnostic use.

A subject of the invention is also an amine compound of formula:



where Trt represents the triphenylmethyl group.

20 The present invention makes it possible to overcome the drawbacks of the state of the art. More particularly it provides a method for native ligation of polypeptides, which is both effective and simpler to implement than the previous methods, including on an industrial scale.

25 This is achieved through the development of a reaction scheme in which a polypeptide modified at the C-terminal end with a bis(mercaptoethyl)amino group reacts with a polypeptide having a cysteine at the N-terminal end (or another amino acid comprising a thiol function) to form a native amide bond.

According to certain particular embodiments, the invention also has one or preferably several of the advantageous features listed below.

- 30 – The method of ligation according to the invention optionally uses unprotected polypeptide reagents, in particular when a single ligation is carried out. The use of protected polypeptides is difficult owing to their low solubility, and because in addition it requires a step of deprotection after ligation, leading to an additional cost and
- 35 the possibility of degradation. Conversely, the invention therefore makes it possible to avoid the drawbacks associated with protected polypeptides, in particular when a single ligation is carried out. The method according to the invention leads directly to

the formation of a native bond at the point of ligation, without it being necessary to carry out deprotection after ligation.

- The method of ligation according to the invention is based on the use of polypeptides modified with chemically stable functional groups, which are easy to introduce using conventional techniques of peptide synthesis.
- The invention allows the use of proteinogenic amino acids for synthesis of the peptide fragments. Thus, there is no need to have recourse to the manufacture of amino acid derivatives (such as keto acids for example), which complicates the synthesis considerably.
- Assembly of the polypeptide reagents can be carried out in standard fashion, for example using Fmoc/tert-butyl chemistry. Consequently, the method according to the invention is compatible with the automated industrial synthesis processes currently available. The amino acids and appropriate solid supports are currently available in large volume and at low cost.
- The invention provides for ligation in an aqueous medium, which is therefore compatible with the solubility of the peptides and of the proteins.
- The ligation reaction according to the invention can be carried out efficiently at a pH close to 7.5, i.e. under conditions compatible with complex polypeptides or proteins.
- The ligation reaction according to the invention offers the possibility of self-ligation of a polypeptide, and therefore of manufacture of cyclic polypeptides.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows the monitoring, by RP-HPLC (reverse-phase high-performance liquid chromatography), of native ligation between polypeptide 1c and polypeptide 2, to obtain polypeptide 3c, according to Example 7. The bottom plot corresponds to the time point $t=10$ min; the middle plot corresponds to the time point $t=18$ h; and the top plot corresponds to the time point $t=43$ h.

Figures 2a and **2b** show the monitoring, by RP-HPLC (reverse-phase high-performance liquid chromatography), of native ligation between polypeptide 1d and polypeptide 2, to obtain polypeptide 3d, according to Example 7. Plot A corresponds to the time point $t=0$; plot B corresponds to

the time point $t=1$ h; plot C corresponds to the time point $t=3$ h; plot D corresponds to the time point $t=5$ h; and plot E corresponds to the time point $t=22$ h.

5 **Figure 2c** shows the deconvoluted mass spectrometry spectrum for the peak of polypeptide 3d obtained at the time point $t=22$ h (**Figure 2b**).

Figures 3a to 3c show the monitoring, by RP-HPLC (reverse-phase high-performance liquid chromatography), of native ligation between polypeptide 1f and polypeptide 2, to obtain polypeptide 3f, according to Example 7. Plot A corresponds to the time point $t=0$; plot B corresponds to
10 the time point $t=1$ h; plot C corresponds to the time point $t=3$ h; plot D corresponds to the time point $t=6$ h; and plot E corresponds to the time point $t=27$ h.

Figure 3d shows the deconvoluted mass spectrometry spectrum for the peak of polypeptide 3f obtained at the time point $t=27$ h (**Figure 3c**).

15

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

A more detailed, non-limitative description of the invention is presented below.

By "polypeptide" is meant, in the context of the present application, a
20 linear chain of amino acid residues (greater than or equal to two in number) linked together by peptide bonds. The "polypeptides" within the meaning of the present application can therefore be for example oligopeptides, peptides or proteins according to the generally accepted definition of these terms. The amino acid residues present in the polypeptides according to the invention
25 can be selected from proteinogenic or non-proteinogenic amino acid residues. Preferably, they are selected from the twenty proteinogenic amino acid residues.

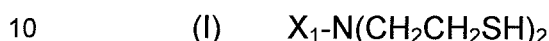
The notation of the polypeptides runs from the N-terminal end to the C-terminal end. The amino acid residues present along the polypeptide chain
30 are designated according to the usual one-letter or three-letter code. An amino acid residue is a polypeptide fragment of formula $-\text{NH}-(\text{CH}-\text{R})-(\text{C}=\text{O})-$, in which R represents a side chain, different from one amino acid to the next.

By "peptide fragment" is meant, in the context of the present application, a portion of polypeptide comprising at least one amino acid
35 residue. A peptide fragment, within the meaning of the present application, can therefore be for example: a sequence of amino acid residues (such as -AHG- or -Ala-His-Gly-) if the peptide fragment comprises neither the N-terminal end nor the C-terminal end of the polypeptide; or a sequence of

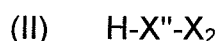
amino acid residues having a group at its N-terminal end (such as H-AHG- or H-Ala-His-Gly-) if the peptide fragment comprises the N-terminal end of the polypeptide; or a sequence of amino acid residues having a group at its C-terminal end (such as -AHG-OH or -Ala-His-Gly-OH) if the peptide fragment
 5 comprises the C-terminal end of the polypeptide.

Native ligation of polypeptides

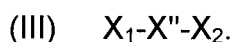
The invention provides a method for native ligation of polypeptides, according to which a polypeptide of formula:



reacts with a polypeptide of formula:



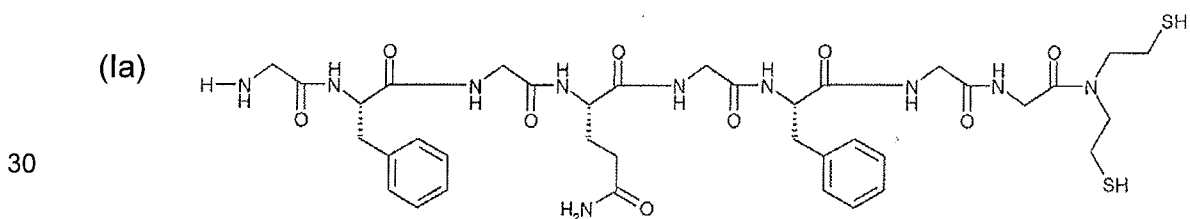
to supply a polypeptide of formula:



15 The polypeptide of formula (I) comprises a peptide fragment X_1 (said peptide fragment comprising the N-terminal end of the polypeptide) and a functional group $-N(CH_2CH_2SH)_2$ at the C-terminal end (bound to the (C=O) termination of the amino acid residue in C-terminal position).

The peptide fragment X_1 is of the form $Y_1-AA_1AA_2...AA_n$. Y_1 is an N-terminal group, preferably a hydrogen atom, but optionally also any group substituting for the primary or secondary amines known to a person skilled in the art, for example an acyl group and in particular an acetyl group. n is an integer greater than or equal to 2. Each AA_i represents an amino acid residue.
 20

25 An example of a polypeptide of formula (I) is polypeptide 1a (see Example 3 below) of formula:



In this example, the peptide fragment X_1 is H-GFGQGFGG.

35 The polypeptide of formula (I) preferably comprises between 2 and 300 amino acid residues, preferably between 5 and 100 amino acid residues, more particularly preferably between 8 and 50 amino acid residues.

The polypeptide of formula (II) comprises a hydrogen atom and a residue X'' at the N-terminal end. The residue X'' is an amino acid residue

comprising a thiol function. This thiol function can in particular be a beta-amino thiol function (in which case the residue X" preferably represents the cysteine residue) or a gamma-amino thiol function (in which case the residue X" preferably represents the homocysteine residue).

5 Throughout the description which follows, according to a particular embodiment, X" can be read as representing a cysteine residue (Cys).

According to the notation used above, X₂ represents a peptide fragment, which comprises the C-terminal end of the polypeptide of formula (II) as well as all of the amino acid residues of this polypeptide, except the N-terminal residue.

10 The peptide fragment X₂ is of the form AA₂'AA₃'...AA_n'-Y₂. Y₂ is an end group, preferably an -OH or -NH₂ group or an -OR or -NRR' group, R and R' each representing an alkyl or aryl group. n is an integer greater than or equal to 2. Each AA_i' represents an amino acid residue.

15 The polypeptide of formula (II) preferably comprises between 2 and 300 amino acid residues, preferably between 5 and 100 amino acid residues, more particularly preferably between 8 and 50 amino acid residues.

The polypeptide of formula (II) can for example be obtained by a usual method of peptide synthesis, in particular a method of solid-phase synthesis.

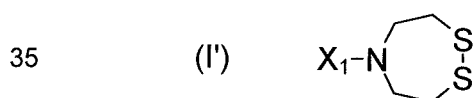
20 It can also be obtained by means of a preceding native ligation (see below).

Each of the polypeptides of formula (I) and (II) preferably comprises only amino acid residues selected from the twenty proteinogenic amino acid residues. However, according to a particular embodiment, the polypeptides of formula (I) and (II) comprise one or more non-proteinogenic amino acid residues.

25 The amino acid residues of the polypeptides of formula (I) and (II) can optionally be protected by groups protecting the side chains.

For the ligation reaction to take place correctly, the presence of the two free thiol groups on the polypeptide of formula (I) is essential. The ligation is said to be native because the peptide fragment X₁ is linked to the peptide fragment X"-X₂ by an amide bond.

It is possible to carry out the above ligation reaction by bringing the polypeptide of formula (II) into contact with a polypeptide of formula:



provided that a compound that reduces the disulphide bonds, which can preferably be a thiol compound such as 4-mercaptophenylacetic acid

(MPAA), dithiothreitol (DTT), thiophenol (and derivatives thereof), an alkylthiol (in particular benzyl mercaptan) or a phosphine such as tris(2-carboxyethyl)phosphine (TCEP), is used during the reaction. The combined use of several of these compounds is also appropriate, for example the use
5 of MPAA and TCEP.

In fact, the polypeptide of formula (I') is then reduced *in situ* and supplies the polypeptide of formula (I) for the ligation reaction.

In general, the ligation reaction starting from the polypeptide of formula (I') as reagent can be more practical to implement than the ligation reaction
10 directly with the polypeptide of formula (I). In fact, the polypeptide of formula (I) has a natural tendency to oxidize to the polypeptide of formula (I'), in particular under the action of the oxygen of the air. For example, it is possible for the polypeptide of open form (I) to oxidize over time when it is stored in lyophilized form. In other words, a preparation of the polypeptide of formula
15 (I) generally partly contains, inevitably, the polypeptide of formula (I'). The presence of these two forms may complicate characterization and purification. That is why it may be simpler to implement the ligation reaction by bringing the polypeptide of formula (I') into contact with the polypeptide of formula (II), the polypeptide with cyclic termination of formula (I') being
20 reduced *in situ* to the open polypeptide of formula (I).

For the same reasons, even when the ligation reaction is carried out directly by bringing the polypeptide of formula (I) into contact with the polypeptide of formula (II), it is preferable if one or more of the
25 aforementioned compounds that reduce the disulphide bonds are used during the reaction.

Preferably, MPAA, when it is present, is used at a concentration comprised between 1 and 500 mM, for example at a concentration of approximately 200 mM during the reaction.

Preferably, TCEP, when it is present, is used at a concentration
30 comprised between 1 and 200 mM, for example at a concentration of approximately 80 mM during the reaction.

In the case where the N-terminal amino acid residue of polypeptide (I) comprises a thiol function, the latter must be protected during ligation, otherwise there will be a competing reaction of cyclization of the polypeptide
35 of formula (I). Alternatively, the alpha amine function can be protected in order to avoid the cyclization reaction. It is possible for example to use protection of the thiazolidine type, which protects the thiol and the alpha amine simultaneously.

The ligation reaction preferably takes place in the liquid phase, and in particular in an aqueous medium, for example in a phosphate buffer. Preferably, this reaction is carried out at a pH comprised between 6.5 and 8.5, more particularly preferably at a pH comprised between 7 and 8 and ideally at a pH close to 7.5.

The ligation reaction is preferably carried out at a temperature comprised between 0 and 50°C, and ideally at a temperature of approximately 37°C. The reaction time is adjusted depending on the choice of reagents and other reaction conditions. The appropriate time can also be adjusted according to the results of liquid chromatography – mass spectrometry analysis during the reaction. The appropriate time will typically be from a few hours to a few days.

Each of the polypeptides of formula (I) and (II) is preferably present at a concentration comprised between 0.01 and 50 mM, during the reaction. The ratio of molar concentration between the polypeptides of formula (I) and (II) during the reaction is preferably comprised between 2:3 and 3:2.

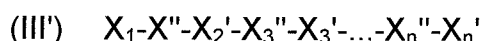
The ligation reaction described above can be followed by a step of purification of the polypeptide of formula (III) obtained, for example by liquid chromatography or by any other usual technique.

Production of a polypeptide with several successive native ligations

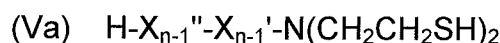
The invention also makes it possible to produce polypeptides using a succession of several ligation reactions as described above. This may prove appropriate for obtaining large polypeptides, for example polypeptides comprising more than approximately 100 amino acid residues. In fact, in such cases the manufacture of polypeptides of formulae (I) and (II) by direct synthesis may have a low yield, and it is therefore advantageous to use two or more than two successive ligations, so that only polypeptides comprising for example less than approximately 50 amino acid residues have to be synthesized directly.

As an example, the use of two successive ligations makes it possible to obtain a polypeptide comprising approximately 150 amino acid residues without requiring direct synthesis of polypeptides comprising more than approximately 50 amino acid residues; the use of three successive ligations makes it possible to obtain a polypeptide comprising approximately 200 amino acid residues without requiring direct synthesis of polypeptides comprising more than approximately 50 amino acid residues.

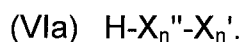
Thus, the method according to the invention makes it possible to obtain a polypeptide of formula (III) in which the peptide fragment X_2 is of the form $X_2'-X_3''-X_3'-\dots-X_n''-X_n'$ (n being an integer greater than or equal to 3; each X_i' , for i an integer between 2 and n , being a peptide fragment; and each X_i'' , for i an integer between 3 and n , being a residue X'' , i.e. an amino acid residue comprising a thiol function, and in particular a cysteine residue according to a particular embodiment) using $n-1$ successive ligations. In other words the polypeptide obtained has in this case the formula:



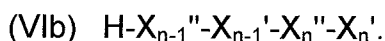
The first ligation reaction involves on the one hand a polypeptide of formula



and on the other hand a polypeptide of formula



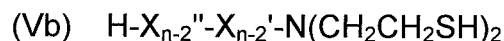
This ligation reaction is exactly the same as that described in the previous section. It leads to production of the polypeptide of formula



The thiol function or the N-terminal amine function (or the thiol function and the amine function) of the amino acid residue X_{n-1}'' must be protected in the polypeptide of formula (Va) during ligation, otherwise there will be a competing reaction of cyclization of the polypeptide of formula (Va). Protection of the thiazolidine type, for example, can be used for this.

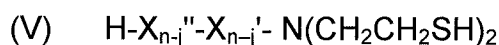
At the end of the ligation reaction, the thiol function of the amino acid residue X_{n-1}'' must be deprotected in the polypeptide of formula (VIb) in order to allow the following ligation reaction.

The second ligation reaction involves on the one hand a polypeptide of formula:

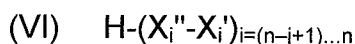


and on the other hand the polypeptide of formula (VIb) obtained previously. The thiol function of the amino acid residue X_{n-2}'' must be protected in the polypeptide of formula (Vb), otherwise there will be a competing reaction of cyclization of the polypeptide of formula (Vb). Protection of the thiazolidine type, for example, can be used for this. The reaction of ligation of the polypeptide of formula (Vb) with the polypeptide of formula (VIb) is then followed by deprotection of the thiol function of the amino acid residue X_{n-2}'' prior to the following ligation reaction.

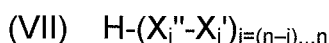
The following ligation reactions are of the same type. Generally, ligation reaction number j (for j an integer comprised between 1 and $n-2$) involves a polypeptide of formula



5 and a polypeptide of formula:



to form a polypeptide of formula:



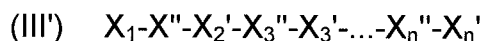
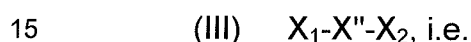
10 Finally, the last (i.e. the $n-1^{th}$) ligation reaction involves the polypeptide of formula:



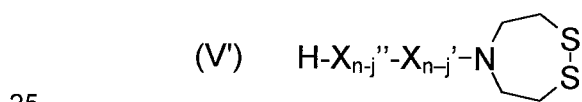
and the polypeptide of formula:



to form the polypeptide of formula:



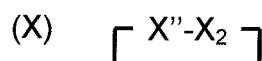
Each successive ligation reaction can be carried out as described in the section "native ligation of polypeptides". In particular, it may be advantageous to carry out the ligation reaction number j (for j an integer comprised between 1 and $n-2$) by bringing the polypeptide of formula (VI) into contact with the polypeptide of formula:



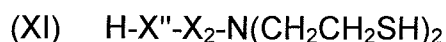
in the presence of one or more of the aforementioned compounds that reduce disulphide bonds, the polypeptide of formula (V') then being reduced *in situ* and supplying the polypeptide of formula (V) for the ligation reaction.

30 Production of a cyclic polypeptide by native self-ligation

The principles used for native ligation described above can also be used for producing cyclic polypeptides, by native self-ligation of a polypeptide (ligation of one end of the polypeptide with the other end of the same polypeptide). In general, the invention thus proposes a method for manufacturing a cyclic polypeptide of formula:



where X_2 represents a peptide fragment, and X'' represents an amino acid residue comprising a thiol function, by a reaction of ligation of a polypeptide of formula:



5 with itself.

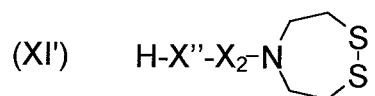
The polypeptide of formula (XI) preferably comprises between 2 and 300 amino acid residues, preferably between 5 and 100 amino acid residues, more particularly preferably between 8 and 50 amino acid residues.

The polypeptide of formula (XI) comprises a hydrogen atom and a
10 residue X'' at the N-terminal end, X'' having the meaning given above. X_2 represents in this case a peptide fragment of the form $AA_1AA_2...AA_n$ where n is an integer greater than or equal to 1 and each AA_i represents an amino acid residue.

The polypeptide of formula (XI) preferably comprises only amino acid
15 residues selected from the twenty proteinogenic amino acid residues. However, according to a particular embodiment, the polypeptide of formula (XI) comprises one or more non-proteinogenic amino acid residues.

The amino acid residues of the polypeptide of formula (XI) can optionally be protected by groups protecting the side chains.

20 It is possible to carry out the above ligation reaction by bringing the polypeptide of formula (XI'):



25 into contact with at least one compound that reduces the disulphide bonds, which is preferably as described above. In fact, the polypeptide of formula (XI') is then reduced *in situ* and supplies the polypeptide of formula (XI) for the ligation reaction.

In general, even when the ligation reaction is carried out directly
30 starting from the polypeptide of formula (XI), it is preferable if one or more of the aforementioned compounds that reduce the disulphide bonds are used during the reaction.

In general, cyclization of the polypeptide of formula (XI) is unaffected by competing multimerizations, if the reaction is carried out in sufficiently
35 dilute conditions. It is possible for example to use a concentration of polypeptide of formula (XI) comprised between 0.01 and 50 mM, typically of approximately 1 mM (or optionally between 0.01 and 0.1 mM if there is a serious risk of multimerizations).

Moreover, the preferred conditions of implementation of the ligation reaction are the same as those described above for the reaction starting from the polypeptides of formula (I) and (II).

5 The ligation reaction described above can be followed by a step of purification of the cyclic polypeptide of formula (X) obtained, for example by liquid chromatography or by any other usual technique.

Method for manufacturing the polypeptides of formula (I), (V) and (XI)

10 The polypeptides of formula (I), (V) and (XI) are compounds that are useful for implementation of the ligation reaction described above. A subject of the invention is therefore also these polypeptides of formula (I) (or of formula (V) or (XI)) as such, as well as a method by which they can be manufactured.

15 The method for manufacturing the polypeptides of formula (I) (or of formula (V) or (XI)) involves two main steps:

- a step of peptide synthesis; and
- a step of C-terminal functionalization.

20 The invention provides two main variants of this method. According to the first variant, peptide synthesis precedes functionalization. According to the second variant, peptide synthesis follows functionalization. The second variant makes it possible to obtain a higher yield and is simpler to implement on an industrial scale.

According to the first variant, the first step (step of peptide synthesis) makes it possible to obtain the polypeptide of formula:

25 (IX) $X_1\text{-OH}$

This step of peptide synthesis can be carried out according to any method known to a person skilled in the art. It can in particular be carried out in the liquid phase or, preferably, in the solid phase.

30 Schematically, the peptide synthesis comprises a succession of couplings of amino acids starting from a primer (initial amino acid or peptide fragment resulting from previous additions of amino acids) and deprotections. More precisely, the peptide synthesis can comprise successively:

- (a) supply of a peptide fragment having an unprotected N-terminal end, and of an amino acid protected at its N-terminal end;
- 35 (b) establishment of a peptide bond between the amino acid and the peptide fragment, at the N-terminal end of said peptide fragment;
- (c) deprotection of the N-terminal end of the bound amino acid, to supply the peptide fragment of the following step (a).

In the case of solid-phase peptide synthesis, the peptide fragment (primer) is bound to a solid support at its C-terminal end. The solid support is preferably a polymer in the form of insoluble or soluble particles (beads). It is possible for example to use resins based on polystyrene, polyacrylamide, polyethylene glycol, cellulose, polyethylene, polyester, latex, polyamide, polydimethylacrylamide and resins derived therefrom. It is also possible to use a silica gel or glass beads as solid support.

The peptide fragment and the solid support are linked together via an appropriate functional group, called a "linker". Thus, firstly, the amino acid corresponding to the C-terminal end of the polypeptide to be synthesized is fixed on the linker functional groups of the solid support (protecting the amine function of the amino acid during coupling and then deprotecting it to make it available for the following reaction), which constitutes the first primer, then the following amino acids are added according to the succession of reactions mentioned above.

In the course of the various coupling reactions, it is advantageous to use an activating compound, in particular a carbodiimide (for example dicyclohexylcarbodiimide or diisopropylcarbodiimide) in the presence of a triazole (for example 1-hydroxy-benzotriazole or 1-hydroxy-7-azabenzotriazole), or a phosphonium or uronium salt of a non-nucleophilic anion (for example HBTU, HATU, TBTU or PyBOP); or to use activated amino acids in the form of acid halides, for example acid fluorides.

In the case of a solid-phase synthesis, and once the last amino acid coupling reaction has been carried out, a reaction of separation (or cleavage) of the polypeptide from its solid support is provided for.

In the course of the different coupling reactions, the N-terminal ends of the amino acids are advantageously protected by a protective group, preferably an Fmoc group (9H-fluoren-9-ylmethoxycarbonyl) or a t-Boc group (tert-butoxycarbonyl) or NSC group (2-(4-nitrophenylsulphonyl)ethoxycarbonyl).

Similarly, the side chains of the amino acid residues are preferably protected during the various coupling reactions by one or more suitable protective groups, for example a tert-butyl group for the chains comprising a carboxylic function.

In this case, once the last amino acid coupling reaction has been carried out, a reaction of deprotection of the side chains can be provided for. It should, however, be noted that it may be preferable to keep all of the

protections (apart from an optional protection of the COOH function at the C end) with a view to the functionalization step.

At the end of the step of peptide synthesis, the polypeptide of formula (IX) is functionalized.

5 The functionalization step comprises successively:

- Optionally protection of the N-terminal end of the polypeptide of formula (IX) with a protective group, preferably selected from the family of the carbamates, amides or alkyl groups, and in particular a tert-butoxycarbonyl (t-Boc), Fmoc (9H-fluoren-9-ylmethoxycarbonyl), trifluoroacetyl or triphenylmethyl group.
- 10 – Also optionally, protection of the functions of the side chains of the amino acid residues of the polypeptide of formula (IX), and quite particularly of the amine functions (preferably by means of the above protective groups) and of the carboxylic functions (for example by means of tert-butyl groups).
- 15 – Alternatively, and according to a simpler embodiment, the polypeptide of formula (IX) can be supplied directly in a form in which all of the amine and carboxylic functions are protected, by providing selective deprotection of the COOH function of the C-terminal end.
- 20 – Coupling of the polypeptide of formula (IX) with an amine compound of formula:

$$(VIII) \quad NH(CH_2-CH_2-S-G_1)_2$$

$$G_1 \text{ being a protective group.}$$
- 25 – Optionally deprotection of the polypeptide.

Regarding the amine compound of formula (VIII), G_1 is preferably selected from the groups supplying a thioether, thioester (for example acetyl) or disulphide (for example tert-butylsulphenyl) function. More particularly preferably, G_1 is the triphenylmethyl group. In this case, the amine compound is bis({2-[triphenylmethyl]sulphanyl}ethyl)amine. Regarding a method of preparation of the amine compound of formula (VIII), reference may be made to Example 1 below.

An activator is advantageously present during the coupling reaction, for example benzotriazol-1-yl-oxytripyrrolidinophosphonium hexafluorophosphate (PyBOP) or bromo-trispyrrolidinophosphonium hexafluorophosphate (PyBROP) or the C-terminal amino acid itself activated in the form of a halogenated derivative (in particular in the form of an amino acid fluoride or amino acid chloride), and the latter can be preformed or

formed in situ using suitable reagents known to a person skilled in the art. Among the halides of amino acids, the amino acid fluorides are preferred, preformed by reaction with 1,3,5-trifluorotriazine or formed in situ with the aid of TFFH (tetramethylfluoroformamidinium hexafluorophosphate).

5 In general, any reagent allowing activation of the carboxylic acid function of the amino acid known to a person skilled in the art can also be envisaged, such as HBTU, TBTU, HATU, BOP, etc. (reference may be made for example to *Chemical approaches to the synthesis of peptides and proteins* by Lloyd-Williams, P., Albericio, F., Giralt, E., 1997, CRC Press).
10 PyBOP, PyBROP, BOP or more generally the phosphoniums are preferred.

At the end of the functionalization step, the polypeptide of formula (I) is obtained. It is advantageous at this stage to provide a step of purification of the compound, for example by liquid chromatography.

15 According to the second variant of the method for producing a polypeptide of formula (I), the functionalization step precedes the step of peptide synthesis. This second variant is applied in the solid phase. Thus, the functionalization step consists, in this embodiment, of creating a primer solid support from a previously functionalized solid support.

20 A soluble or insoluble polymer is used as solid support, the insoluble polymer preferably being in the form of particles (beads). For example, it is possible to use a resin based on polystyrene (preferably) or based on polyacrylamide, polyethylene glycol, cellulose, polyethylene, polyester, latex, polyamide, polydimethylacrylamide, polyethylene glycol-polystyrene copolymer, polyethylene glycol-polyacrylamide copolymer or a resin derived
25 therefrom.

Moreover, the solid support has linker groups, which are preferably chloro-triphenylmethyl (or chlorotrityl) groups, where the triphenylmethyl is optionally substituted with one or more substituents, in particular selected from the substituents chlorine, methoxy, methyl, fluorine and cyano.

30 As examples of solid support, polystyrene resins having trityl chloride, 2-chlorotrityl chloride, 4-methyltrityl chloride or 4-methoxytrityl chloride linker groups may be mentioned. Solid supports of this kind are available commercially, for example from Glycopep.

35 According to another embodiment, the solid support has linker groups that are groups of the trityl-alcohol type, i.e. OH-Trt-CO-NH- groups, where the triphenylmethyl (Trt) is optionally substituted with one or more substituents, in particular selected from the substituents chlorine, methoxy, methyl, fluorine and cyano. Solid supports having such linker groups are

described for example in Quibell, JACS 1995, 117, 11656-11668, and are available commercially, for example in the ChemMatrix® range of polyethylene glycol solid supports.

5 The use of solid supports of this type requires a preliminary step of activation of the solid support:

- either with a brominated agent (in particular acetyl bromide) for modifying the linker groups in the form Br-Trt-CO-NH-;
- or with a chlorinated agent (in particular oxalyl chloride) for modifying the linker groups in the form Cl-Trt-CO-NH-.

10 An activation step of this type is described for example in Harre et al., Reactive & Functional Polymers 1999, 41, 111-114.

Alternatively, the resin can be reacted directly with the amine $\text{NH}(\text{CH}_2\text{-CH}_2\text{-SH})_2$ in the presence of $\text{BF}_3\cdot\text{Et}_2\text{O}$, according to Singh, S. et al., J. Org. Chem. 2004, 69, 4551-4554.

15 The use of solid supports of this type may make it possible to use skeletons of resin of the polyethylene glycol or polyethylene glycol-polystyrene type, which are more suitable for preparing long polypeptides than the resins of the polystyrene type.

Preferably, the particles have a Dv_{50} comprised between 1 and 20 1000 μm . Dv_{50} is defined as the 50th percentile of the particle size distribution, i.e. 50% of the particles have a size below Dv_{50} and 50% have a size above Dv_{50} . In general, Dv_{50} is characteristic of the granulometric profile (volumetric distribution) of the particles, and it can be determined by laser granulometry (for a size below 200 μm), or by sieving (for a size above 25 200 μm).

The functionalized solid support is prepared by coupling the amine compound of formula:



to the aforementioned solid support. The amine compound (VIII') can itself be 30 obtained by deprotection of the amine compound of the above formula (VIII), in which G_1 is a protective group.

Coupling is carried out in an acid medium in order to limit the risks of unmasking the secondary amine, which would lead to secondary reactions.

The trityl chloride groups in excess are preferably neutralized, for 35 example with methanol. It is then important to add a base to neutralize the HCl formed.

It can be provided that preparation of the functionalized solid support forms an integral part of the second variant of the method for manufacturing

the polypeptides of formula (I). Alternatively, the functionalized solid support can be prepared in advance and separately, so as to be ready for use in the context of the second variant of the method for manufacturing the polypeptides of formula (I).

5 The functionalized solid support is a polymer resin support that comprises a main skeleton (of polystyrene, polyethylene glycol-polystyrene, polyacrylamide, polyethylene glycol, cellulose, polyethylene, polyester, latex, polyamide, polydimethylacrylamide, polyethylene glycol-polystyrene
10 copolymer, polyethylene glycol-polyacrylamide copolymer type or a derivative thereof, as required) and $\text{NH}-(\text{CH}_2\text{CH}_2-\text{S}-\text{Trt})_2$ groups bound to the main skeleton by the two Trt groups, or $\text{NH}-(\text{CH}_2\text{CH}_2-\text{S}-\text{Trt}-\text{CO}-\text{NH})_2$ groups, bound to the main skeleton by the two NH functions, in the case when the starting solid support is of the trityl-alcohol type.

15 In the above, Trt represents a triphenylmethyl group optionally substituted with one or more substituents in particular selected from the substituents chlorine, methoxy, methyl, fluorine and cyano.

Thus, this polymer resin support is essentially devoid of free thiol functions, and has secondary amine functions (disulphanylethylamine functions).

20 Then, an amino acid is coupled to the functionalized solid support.

Preferably the amino acid is protected at its N-terminal end by a protective group that is labile in the presence of a base, preferably selected from the 2-(4-nitrophenylsulphonyl)ethoxycarbonyl (NSC) group or Fmoc.

25 Preferably, the amino acid comprises protective groups on some or all (preferably all) of the functions present on its side chain, and in particular the carboxylic, amine, alcohol, phenol, guanidine (for arginine) and imidazole (for histidine) functions. Protective groups of this kind are known to a person skilled in the art. Reference may be made for example to the reference work *Protective groups in organic synthesis*, 2nd edition, T. Greene and P.
30 Wuts, John Wiley & Sons, Inc.

Preferably, the amino acid is activated in the presence of PyBOP or of BOP or more particularly preferably in the presence of PyBROP, or in the form of a halide, in particular fluoride (i.e. a fluorine atom is bound to the acyl group of the amino acid residue).

35 The amino acid reacts with the secondary amine function present on the functionalized solid support to form an amide bond. After coupling of the amino acid, deprotection of the latter can optionally be carried out.

Consequently, at the end of the functionalization step, a polymer resin support is obtained, a so-called primer support, comprising $G_2\text{-NH-CHR-CO-N(CH}_2\text{CH}_2\text{-S-Trt-)}_2$ groups (R representing an amino acid side chain), which can also be designated $G_2\text{-AA-N(CH}_2\text{CH}_2\text{-S-Trt-)}_2$ (AA representing an amino acid residue), these groups being bound to the main skeleton by the two Trt groups; or $G_2\text{-AA-N(CH}_2\text{CH}_2\text{-S-Trt-CO-NH-)}_2$ groups, bound to the main skeleton by the two NH functions.

It will be recalled that Trt denotes a triphenylmethyl group optionally substituted with one or more substituents in particular selected from the substituents chlorine, methoxy, methyl, fluorine and cyano. Moreover, G_2 represents a hydrogen atom or an amine function protecting group, depending on whether or not the alpha amine group of the amino acid has been deprotected. Finally, the functions of the side chain R of the amino acid residue AA can advantageously be protected, as mentioned above.

The primer support thus obtained (with or without protective groups) is also an object of the invention as such.

Then the step of peptide synthesis is carried out, similarly to what was described above in relation to the first embodiment, the initial primer being supplied by the amino acid coupled to the activated support.

Once the last amino acid coupling reaction has been carried out, a reaction of separation (or cleavage) of the polypeptide from its solid support is provided, and if necessary the appropriate deprotections, after which the polypeptide of formula (I) is obtained. Just as for the first variant, it is advantageous at this stage to provide a step of purification of the compound, for example by liquid chromatography.

Method for manufacturing the polypeptides of formula (I'), (V') and (XI')

The polypeptides of formula (I'), (V') and (XI') mentioned above can be obtained very easily starting from the polypeptides of formula (I), (V) and (XI) respectively by oxidation in the air, for example in an ammonium bicarbonate buffer at approximately pH 8. Another advantageous possibility consists of using iodine I_2 or the diamide $H_2\text{NCO-N=N-CONH}_2$.

Applications

The polypeptides of formula (I) obtained according to the invention can be used for producing a bank of polypeptides, for example for screening purposes.

They can also be used for manufacturing pharmaceutical compositions, in combination with one or more pharmaceutically acceptable additives (including one or more pharmaceutically acceptable vehicles). As examples of pharmaceutical compositions that can be obtained according to the invention, medicinal products and vaccine preparations may be mentioned.

They can also be used for producing diagnostic kits.

EXAMPLES

The following examples illustrate the invention without limiting it.

Example 1 relates to preparation of the compound bis({2-[triphenylmethyl]sulphanyl}ethyl})amine (compound of formula (VIII)).

Examples 2 and 3 lead to the manufacture of a polypeptide 1a of formula H-GFGQGFGG-N(CH₂CH₂SH)₂ (SEQ ID NO: 1, corresponding to general formula (I) above) according to the first variant of the method for manufacturing a polypeptide of formula (I), described above (liquid-phase synthesis).

Examples 4 and 5 lead to the manufacture of a functionalized resin, having disulphanylethylamine functions.

Example 6 relates to preparation of a so-called "primer" support from the aforementioned functionalized resin, on which a first amino acid is fixed.

Example 7 relates to preparation of the polypeptides 1c (H-ILKEPVHGG-N(CH₂CH₂SH)₂) (SEQ ID No: 2), 1d (H-ILKEPVHGA-N(CH₂CH₂SH)₂) (SEQ ID NO: 3), 1e (H-ILKEPVHGV-N(CH₂CH₂SH)₂) (SEQ ID NO: 4) and 1f (H-ILKEPVHGY-N(CH₂CH₂SH)₂) (SEQ ID NO: 5), compounds corresponding to general formula (I) above, according to the second variant of the method for manufacturing a polypeptide of formula (I), described above (solid-phase synthesis).

Example 8 relates to ligation of the respective polypeptides 1c, 1d and 1f with a polypeptide 2 of formula H-CILKEPVHGV-NH₂ (SEQ ID NO: 6) corresponding to general formula (II), to supply respective polypeptides 3c (SEQ ID NO: 9), 3d (SEQ ID NO: 10) and 3f (SEQ ID NO: 11).

Example 9 relates to the synthesis of polypeptide 1g (H-CHHLEPGG-N(CH₂CH₂SH)₂) (SEQ ID NO: 7), a compound corresponding to general formula (XI) above, according to the second variant of the method for manufacturing a polypeptide of general formula (XI), described above (solid-phase synthesis); as well as cyclization of this polypeptide to supply a cyclic polypeptide corresponding to general formula (X) above.

Example 10 relates to oxidation of the polypeptides 1c, 1d, 1e and 1f to dithiazepanes (compounds corresponding to general formula (I') above).

Example 11 relates to the ligation of polypeptide 1c with a polypeptide 4 (SEQ ID NO: 17) having an N-terminal homocysteine, to supply a polypeptide 5 (SEQ ID NO: 18).

Examples 12, 13 and 14 relate respectively to the synthesis of a polypeptide 6 (SEQ ID NO: 19), a polypeptide 7 (SEQ ID NO: 20) and a polypeptide 8 (SEQ ID NO: 21).

Example 15 relates to the ligation of polypeptide 7 and of polypeptide 8 to form a polypeptide 7-8 (SEQ ID NO: 22), and Example 16 relates to the ligation of polypeptide 6 with polypeptide 7-8 to form a polypeptide 6-7-8 (SEQ ID NO: 23) after deprotection of the thiazolidine present on the N-terminal cysteine of fragment 7-8. This is therefore a construction with two successive ligations. The final polypeptide 6-7-8 is a linear polypeptide of sequence:
 H-IRNCIIGKGRSYKGTVSITKSGI
 KCQPWSSMIPHEHSFLPSSYRGKDLQENYCRNPRGEEGGPWCFSTNPEV
 RYEVCDIPQCSEV-NH₂, the cysteines shown in bold being those involved in the ligations.

Example 1: preparation of bis({2-[triphenylmethyl]sulphonyl}ethyl)amine

1.50 g of bis(2-chloroethyl)amine (8.4 mmol) and 4.65 g of triphenylmethanethiol (2 equivalents, 16.80 mmol) are introduced into a flask and placed under inert atmosphere. With magnetic stirring, 25 mL of anhydrous dimethylformamide (DMF) is added and the reaction mixture is cooled down in an ice bath. 4 equivalents of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) are added dropwise to the mixture. The mixture is left under stirring at ambient temperature for 3 hours and the reaction is monitored by thin-layer chromatography (TLC) (eluent: cyclohexane / ethyl acetate / triethylamine: 8 / 2 / 0.1). After this time, the solvent is evaporated in a rotary evaporator. The white solid obtained is then dissolved in 50 mL of dichloromethane (DCM) and the product is extracted three times with a 5% aqueous solution of KH₂PO₄. The product is then purified by silica gel column chromatography (eluent: cyclohexane / EtOAc / triethylamine (TEA): 8 / 2 / 0.1), obtaining 1.46 g of white amorphous solid (yield: 28%)

The analysis of the product is as follows.

R_f = 0.37 (silica gel, cyclohexane / EtOAc / TEA : 8 / 2 / 0.1); ¹H NMR (300 MHz, CDCl₃) δ 7.41-7.37 (m, 12H, Trt), 7.15-7.29 (m, 18H, Trt), 2.23-2.36 (m, 8H, CH₂), 1.26 (s, 1H, NH); ¹³C (75 MHz, CDCl₃) 154.1; 129.8;

128.1; 126.9; 47.9; 32.6; MALDI-TOF: 243.1 [Trt⁺], 622.3 [M+H]⁺, 644.3 [M⁺+Na⁺].

Example 2: synthesis of the polypeptide H-GFGQGFGG-OH (SEQ ID NO: 8)

5 1 g of Wang resin (charge: 1.1 mmol/g) is put in a reactor and solvated for 30 min in DMF. In parallel, in a flask under inert atmosphere, 3.27 g of Fmoc-Gly-OH (10 equivalents, 11 mmol) is dissolved in 100 mL of anhydrous dichloromethane / DMF mixture (99/1, v/v). A solution of 857 μ L of diisopropyl carbodiimide (5 equivalents, 5.50 mmol) in 5 mL of anhydrous
10 dichloromethane is added, under inert atmosphere, to the amino acid solution at 0°C. The reaction mixture is left under stirring at this temperature for 30 min. After this time, the solvent is evaporated and the white solid obtained is dissolved in 5 mL of DMF. The solution is added to the resin with 0.1 equivalent of DMAP (12.2 mg, 0.1 mmol) in 1 mL of DMF, and then the
15 reaction mixture is left under stirring for 1 hour. The resin is then filtered, washed with 5 mL of DMF, 5 mL of dichloromethane and then dried under vacuum. The final charge of resin (0.95 mmol/g; 86%) is determined by UV quantification of the dibenzofulvene-piperidine adduct released during deprotection of aliquots with a 20% solution of piperidine in DMF.

20 Solid-phase synthesis of polypeptides is carried out using the Fmoc/tert-butyl strategy on Fmoc-Gly-Wang resin (scale of 0.5 mmol) prepared as previously on a microwave peptide synthesizer (CEM μ WAVES, Saclay, France). Coupling is carried out using a 5 times molar excess of each amino acid, the activator HBTU (O-benzotriazole-N,N',N'-
25 tetramethyluronium hexafluorophosphate) is used with a 4.5 times molar excess and the base DiEA (diisopropylethylamine) is used with a 10 times molar excess. The final deprotection and cleavage of the polypeptide from the resin are carried out with 30 mL of a TFA (trifluoroacetic acid) / TIS (triisopropylsilane) / H₂O mixture (95 / 2.5 / 2.5 by volume) for 1 hour. The
30 polypeptide is then obtained by precipitation in a diethyl ether / heptane mixture (1 / 1 by volume), dissolved in H₂O and then lyophilized. The purity of the polypeptide (79%) is determined by HPLC (liquid chromatography) and capillary electrophoresis. LC-MS analysis of the principal polypeptide is in agreement with the structure of the expected polypeptide (C₃₃H₄₃N₉O₁₀
35 calculated 726.32 Da [M+H]⁺, observed 726.50 Da).

Example 3: liquid-phase synthesis of polypeptide 1a (H-GFGQGFGG-N(CH₂CH₂SH)₂) (SEQ ID NO: 1)

102 mg of polypeptide H-GFGQGFGG-OH (SEQ ID NO: 8) (0.14 mmol) is dissolved in a minimum amount of anhydrous dimethylformamide (DMF), and 39 μ L of triethylamine (TEA) (2 equivalents, 0.28 mmol) is added to the solution. With stirring, 42 μ L of di-tert-butyl dicarbonate (Boc₂O) (1.3 equivalent, 0.18 mmol) is added to the reaction mixture and the solution is homogenized by adding anhydrous DMF. The reaction is monitored by HPLC.

174.2 mg of bis({2-[triphenylmethyl]sulphonyl}ethyl)amine (2 equivalents, 0.28 mmol) is added to the preceding reaction mixture. 32 μ L of DIEA (1.3 equivalent, 0.18 mmol) and 94.7 mg of benzotriazol-1-yl-oxytripyrrolidinophosphonium hexafluorophosphate (PyBOP) (1.3 equivalent, 0.18 mmol) are added to the reaction mixture. Coupling is monitored by HPLC. The polypeptide resulting from this coupling step is then precipitated and washed in a large volume of cold diethyl ether. The polypeptide is then dissolved in a minimum amount of DMF, then precipitated and washed a second time in diethyl ether.

12.2 mL of a TFA / TIS / water mixture (95 / 2.5 / 2.5) is added to the protected polypeptide. The solution turns yellow immediately and quickly fades. After 30 min, the polypeptide is precipitated in 300 mL of a cold diethyl ether / heptane mixture (1 / 1). The solution is centrifuged and then the polypeptide is washed twice with the above mixture. The polypeptide is solubilized in water, frozen and then lyophilized. The product is then purified by preparative HPLC (gradient: 0 to 40% of buffer B in 40 min, flow rate: 6 mL/min). 60 mg of purified polypeptide is then obtained after lyophilization (total yield = 50%).

The analysis of the product is as follows.

¹H NMR (500 MHz, DMF-d₇).

Phe₂ (2.98, dd, 1H, H β ; 3.23, dd, 1H, H β ; 4.63, m, 1H, H α ; 7.19-7.33, m, 5H, H_{arom.}); Gln₄ (1.98-2.15, m, 2H, H β ; 2.31, m, 2H, H γ ; 4.37, dt, 1H, H α ; 6.97, s, 1H, NH₂; 7.57, s, 1H, NH₂; 8.09, d, 1H, NH); Phe₆ (2.98, dd, 1H, H β ; 3.23, dd, 1H, H β ; 4.63, m, 1H, H α); Gly_{1, 3, 5, 7, 8} (3.72-4.21, m, 10H, H α ; 8.6, broad s, 3H, NH₃⁺ term.).

Bis(tritylmercaptoethyl)amino group: 2.22 (t, 1H, SH); 2.42 (t, 1H, SH); 2.68 (q, 2H, CH₂); 2.81 (q, 2H, CH₂); 3.5 (t, 2H, CH₂); 3.58 (t, 2H, CH₂).

¹³C NMR (125 MHz, DMF-d₇): Phe₂ (39.7, C β ; 57.5, C α ; C_{arom.}; CO); Gln₄ (30.2, C β ; 34.1, C γ ; 55.9, C α ; CO); Phe₆ (39.7, C β ; 58.2, C α ; C_{arom.}; CO); Gly_{1,3, 5, 7, 8} (C α ; CO).

Bis(tritylmercaptoethyl)amino group: 24.0; 25.0; 52.0; 53.0.

Mass spectrometry: LC-MS $C_{37}H_{52}N_{10}O_9S_2$ $[M+H]^+$ calculated 845.34 Da; observed 845.42 Da.

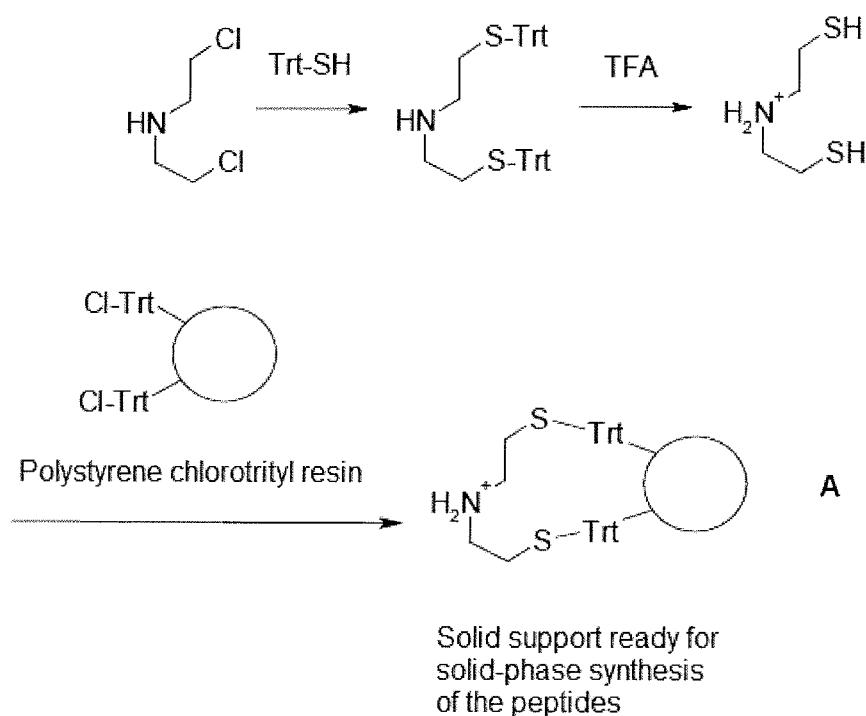
5 Example 4: deprotection of the secondary amine bis({2-[triphenylmethyl]sulphonyl}ethyl)amine

12.5 mL of a TFA / TIS mixture (97.5 / 2.5) is poured onto 77.75 mg of bis({2-[triphenylmethyl]sulphonyl}ethyl)amine (0.125 mmol). The reaction mixture is left under stirring for 30 minutes. The solution is then evaporated to dryness in a rotary evaporator, obtaining a white solid. The solid obtained
10 (compound of formula (VIII')) is solubilized in cyclohexane and evaporated to dryness; the operation is repeated twice.

Example 5: coupling of the deprotected amine to the chlorotriyl resin

893 mg of resin (trityl chloride resin on skeleton of styrene copolymer
15 with 1% of divinylbenzene, 200-400 mesh, 1.4 mmol/g, marketed by Merck under the reference 01-64-0074) is put in a reactor (1.25 mmol). Under argon, the amine from Example 4 is solubilized in 5 mL of anhydrous DMF and deposited on the resin using a gas-tight syringe. The reactor is stirred overnight under aluminium foil. 40.5 μ L of methanol (1 mmol) and 116.5 μ L of
20 lutidine (1 mmol) are added to the resin. After solvolysis for 30 minutes, the resin is washed with 2x2 minutes of DMF, 2x2 minutes MeOH, 2x2 minutes DMF, 2x2 minutes 5% DIEA in DMF and finally 2x2 minutes DMF. Chloranil and Ellman colorimetric tests reveal the presence of a secondary amine and absence of free thiol on the resin.

25 The method for obtaining the functionalized resin of Example 5 corresponds to the following general diagram :



Example 6: coupling of amino acids on the functionalized resin from Example 5 to supply primer supports (functionalized resin bearing a first amino acid)

5 0.5 mmol of Fmoc-AA-F (amino acid protected by an Fmoc group and activated in the form of an acid fluoride) is solubilized in 2 mL of anhydrous DCM and added to the resin from Example 5 (0.125 mmol). Then 82.4 μ L of N-methylmorpholine (0.75 mmol) is added. The reaction is stirred at ambient temperature for 2 hours. The resin is then washed for 5x2 minutes with
10 anhydrous DCM and 3x2 minutes DMF. Chloranil and Ellman colorimetric tests show absence of secondary amine and of free thiol on the resin.

 The final charge of the resin is determined by UV-VIS assay at 290 nm of the dibenzofulvene-piperidine adduct released during deprotection with a 20% solution of piperidine in DMF.

15 This example is implemented with 4 different amino acids: glycine, alanine, valine and tyrosine.

 A charge of 0.15 mmol/g is obtained for glycine; 0.124 mmol/g for alanine; 0.115 mmol/g for valine; and 0.107 mmol/g for tyrosine.

20 It should be noted that for coupling the first amino acid to the solid support, other coupling agents can be used such as PyBOP, PyBrop, HBTU etc. It was found that PyBrop gives the best results and allows direct use of

the amino acids without the need for preactivation using an acid fluoride (which is less practical experimentally).

5 Example 7: solid-phase synthesis of the polypeptides 1c (H-ILKEPVHGG-N(CH₂CH₂SH)₂), 1d (H-ILKEPVHGA-N(CH₂CH₂SH)₂), 1e (H-ILKEPVHGV-N(CH₂CH₂SH)₂) and 1f (H-ILKEPVHGY-N(CH₂CH₂SH)₂)

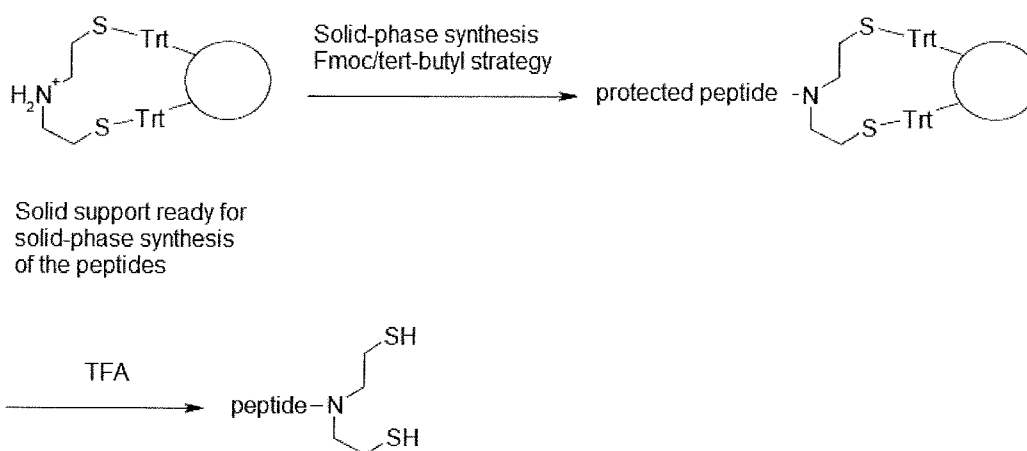
Polypeptide 1c (SEQ ID NO: 2) is obtained from the primer support prepared in Example 6 with glycine.

10 Polypeptide 1d (SEQ ID NO: 3) is obtained from the primer support prepared in Example 6 with alanine.

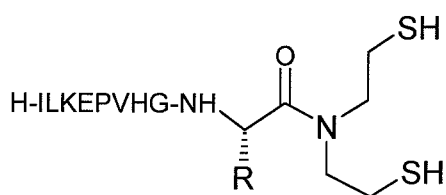
Polypeptide 1e (SEQ ID NO: 4) is obtained from the primer support prepared in Example 6 with valine.

Polypeptide 1f (SEQ ID NO: 5) is obtained from the primer support prepared in Example 6 with tyrosine.

15 The synthesis of the polypeptides can be summarized as follows:



20 The polypeptides obtained in Example 7 have the following general formula:



R= H 1c

R= CH₃ 1d

R= CH(CH₃)₂ 1e

R= p-OHPhCH₂ 1f

The solid-phase synthesis of the various polypeptides is carried out using the Fmoc/*tert*-butyl strategy on the respective resins from Example 6 (scale of 0.1 mmol) on a microwave peptide synthesizer (CEM μ WAVES, 5 Saclay, France). Coupling is carried out using a 5 times molar excess of each amino acid, the activator HBTU is used with a 4.5 times molar excess and the base DiEA is used with a 10 times molar excess.

The final deprotection and cleavage of the polypeptide from the resin 10 are carried out with 10 mL of a TFA/TIS/DMS/H₂O mixture (92.5/2.5/2.5/2.5 by volume) for 1 hour. The polypeptide is then obtained by precipitation in 100 mL of a diethyl ether/heptane mixture (1/1 by volume), dissolved in H₂O and then lyophilized.

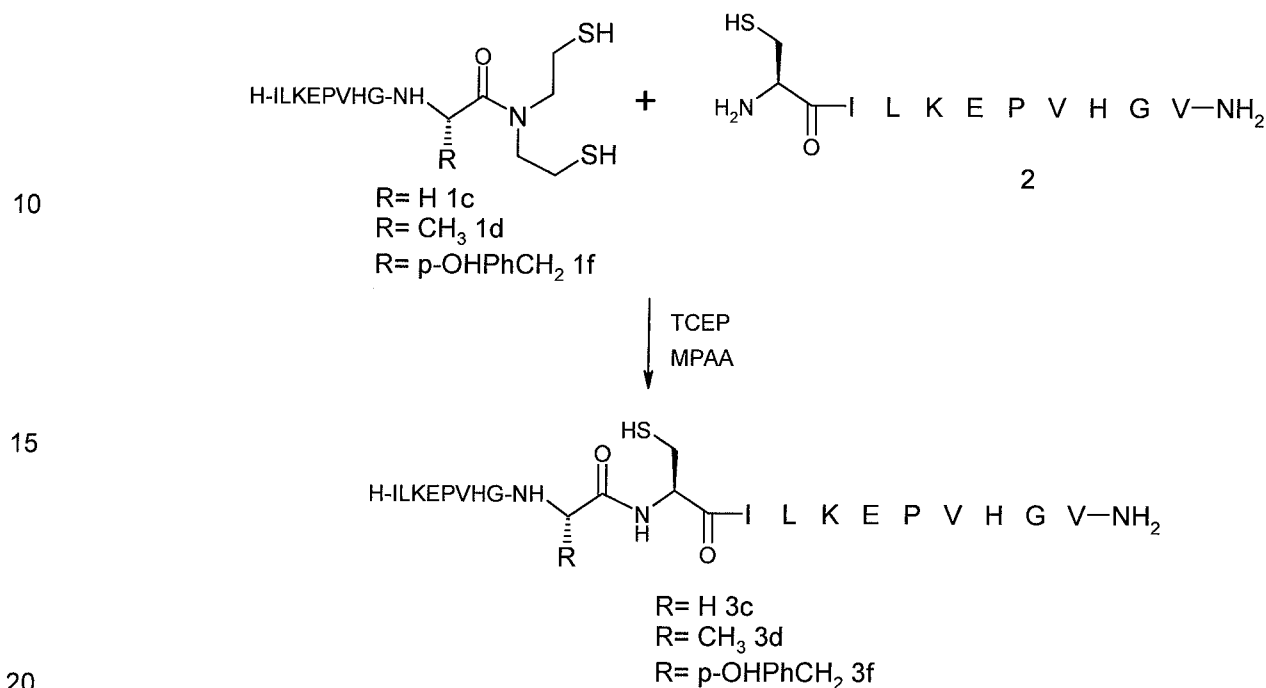
The purity of each polypeptide is determined by HPLC (91% for 15 polypeptide 1c with a glycine, 83% for polypeptide 1d, 80% for 1e, and 88% for 1f). MALDI-TOF analysis of the polypeptides is in agreement with the structure of the expected polypeptide (Peptide 1c C₄₇H₈₁N₁₃O₁₁S₂ [M+H]⁺ calculated 1068.6 Da, observed 1068.5. Polypeptide 1d C₄₈H₈₃N₁₃O₁₁S₂ [M+H]⁺ calculated 1082.6 Da, observed 1082.4. Polypeptide 1e 20 C₅₀H₈₇N₁₃O₁₁S₂ [M+H]⁺ calculated 1110.6 Da, observed 1110.5). Polypeptide 1f C₅₄H₈₇N₁₃O₁₂S₂ [M+H]⁺ calculated 1174.6 Da, observed 1174.6).

The polypeptides are purified on a Nucleosil C18 column in acetonitrile-H₂O (80-20) in TFA, with a gradient from 0 to 30% in 30 min for polypeptide 1c, and a gradient from 0 to 10% in 5 min and then 10 to 25% in 25 25 min for polypeptides 1d and 1e.

The purity determined by HPLC is 96% for polypeptide 1c with an overall yield of 35%, 97% for polypeptide 1d with a yield of 31%, and 99% for polypeptide 1e with a yield of 27%.

Example 8: ligation of polypeptides 1c, 1d and 1f with polypeptide 2 (H-CILKEPVHGV-NH₂)

The respective ligations of polypeptides 1c, 1d and 1f obtained in Example 7 with polypeptide 2 (SEQ ID NO: 6) are carried out according to the following diagram :



These ligations make it possible to obtain the respective polypeptides 3c (of formula H-ILKEPVHGGCILKEPVHGV-NH₂, SEQ ID NO: 9), 3d (of formula H-ILKEPVHGACILKEPVHGV-NH₂, SEQ ID NO: 10) and 3f (of formula H-ILKEPVHGYCILKEPVHGV-NH₂, SEQ ID NO: 11).

25 Ligation of polypeptide 1c.

336 mg of MPAA (2 mmol, 200 mM) and 234 mg of TCEP (800 μ mol, 80 mM) are dissolved in 10 mL of 0.1 M phosphate buffer (pH adjusted to 7.5). 10.2 mg of polypeptide 1c is dissolved in the mixture (7.2 μ mol, 0.72 mM), this solution is added to 15.3 mg of polypeptide 2 H-CILKEPVHGV-NH₂ (10.6 μ mol, 1.06 mM). The mixture is placed under argon and then stirred at 37°C. The product is then purified by RP-HPLC to give 5.9 mg of polypeptide 3c (32%).

Ligation of polypeptide 1d.

35 First, an MPAA/TCEP·HCl solution is prepared. 33.52 mg of MPAA and 57.54 mg of TCEP·HCl are weighed in a 1.5-mL polypropylene tube. 1 mL of 0.1M phosphate buffer at pH=7.3 and then 140 μ L of 6M NaOH are added, leading to complete solubilization of the powders. An additional 20 μ L of 6M NaOH is added to adjust the solution pH to 7.05.

For the actual ligation reaction, 5.99 mg of polypeptide 1d and 9.05 mg of polypeptide 2 are weighed in the same 5-mL glass flask. 600 μ L of the above solution is added. The reaction mixture is put under argon in 3 vacuum/argon cycles, then placed in an oil bath thermostatically controlled to 37°C and stirred using a magnetic bar.

After 26.5 h, the reaction mixture is transferred to a 15-mL polypropylene tube. The reaction flask is rinsed with 3.4 mL of buffer A (water containing 0.05 vol.% of TFA), which is transferred to the 15-mL tube. 4 extractions (4 $\times$ 4 mL) are carried out with ether. The aqueous phase is acidified further by adding 150 μ L of TFA at 10% in water. 4 new extractions (4 $\times$ 4 mL) with ether are repeated.

The aqueous phase is then injected in preparative HPLC (ambient temperature, 230 nm, Nucleosil C18 column 120 A-5 μ m, buffer A (water containing 0.05 vol.% of TFA), buffer B acetonitrile/water 4/1 by volume containing 0.05 vol.% of TFA, flow rate 3 mL/min, gradient 0 to 15% B in 15 min, then 15 to 100% B in 283 min, volume injected 4 mL).

After lyophilization, 8.5 mg of ligation product is collected (yield=77%).

$C_{93}H_{156}N_{26}O_{23}S$ [M+H]⁺ calculated 2038.16, found 2038.07.

Determination of enantiomeric purity for alanine: 1.76% D-enantiomer.

Ligation of polypeptide 1f.

First, an MPAA/TCEP·HCl solution is prepared. 33.63 mg MPAA and 57.37 mg of TCEP·HCl are weighed in a 1.5-mL polypropylene tube. 1 mL of 0.1 M phosphate buffer pH=7.3 and then 140 μ L of 6M NaOH are added, leading to complete dissolution of the powders. The solution pH is adjusted to 7.05 with 6M NaOH.

For the ligation reaction proper, 3.97 mg of polypeptide 1e and 5.75 mg of polypeptide 2 are weighed in the same 5-mL glass flask. 374 μ L of the above solution is added. The reaction mixture is put under argon in 3 vacuum/argon cycles, then placed in an oil bath thermostatically controlled to 37°C and stirred using a magnetized bar.

After 44.5 h, 78.6 μ L (30 eq) of a 1M solution of TCEP·HCl in phosphate buffer adjusted to pH=7.0 with 6N soda is added.

After 4.5 days, the reaction mixture is transferred to a 15-mL polypropylene tube. The reaction flask is rinsed with 3.5 mL of buffer A and acidified with 150 μ L of TFA at 10% in water, which is also transferred to the tube. 3 extractions (3 $\times$ 5.5 mL) are carried out with ether.

The aqueous phase is then injected in preparative HPLC (ambient temperature, 230 nm, Nucleosil C18 column 120 A-5 μ m, buffer A 100%

water containing 0.05% TFA, buffer B acetonitrile/water 4/1 containing 0.05% TFA, flow rate 3 ml/min, gradient 0 to 15% B in 15 min, then 15 to 100% B in 283 min, volume injected 4 mL).

After lyophilization, 3.80 mg of ligation product is collected (yield=54%).

$C_{99}H_{160}N_{26}O_{24}S$ $[M+H]^+$ calculated 2130.18, found 2130.2.

Determination of enantiomeric purity of Tyr: 1.25% D-enantiomer.

Figures 1 to 3d illustrate the monitoring of the ligation reaction for the ligation of polypeptides 1c, 1d and 1f.

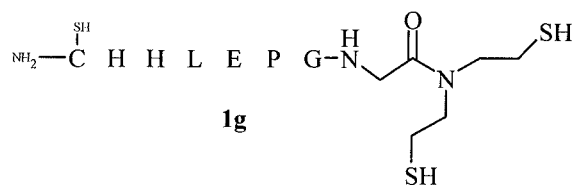
Example 9: solid-phase synthesis of polypeptide 1g (H-CHHLEPGG-N(CH₂CH₂SH)₂) and cyclization of this polypeptide

Polypeptide 1g (SEQ ID NO: 7) was synthesized as with polypeptide 1c.

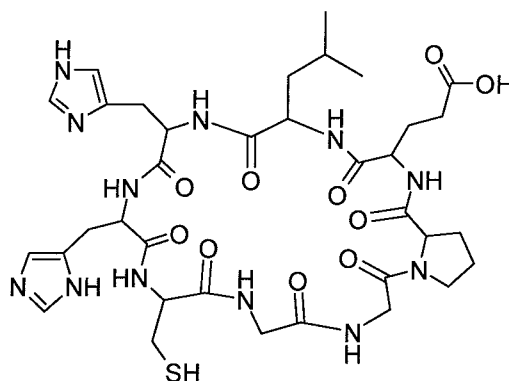
The solid-phase synthesis of polypeptide 1g is carried out using the Fmoc/tert-butyl strategy (scale 50 μ mol) on a microwave peptide synthesizer. Coupling is carried out in the presence of HTBU as activating agent (4.5 eq) and DIEA as base (10 eq). At the end of synthesis, the resin is washed with dichloromethane (2 x 5 mL), with ethyl ether (2 x 5 mL), and then dried. The final deprotection and cleavage of the polypeptide are carried out with 5 mL of TFA/TIS/H₂O/DMS mixture, 9.25/0.25/0.25/0.25 by volume for one hour. The polypeptide is precipitated in 50 mL of an ether/heptane mixture (1/1), dissolved in water and then lyophilized.

Polypeptide 1g: $C_{39}H_{61}N_{13}O_{10}S_3$, MALDI-TOF analysis $[M+H]^+$ calculated 968.19, observed 968.2.

Polypeptide 1g is then cyclized to provide polypeptide 3g, according to the following diagram :



MPAA/TCEP
Phosphate pH 7.5
37°C



The conditions used for cyclization are identical to the conditions used for ligation of polypeptide 1c to polypeptide 2.

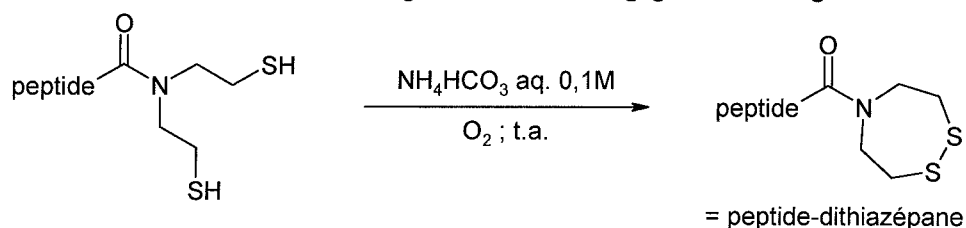
33.64 mg of MPAA (200 mM) and 22.9 mg of TCEP (80 mM) are dissolved in 1 mL of 0.1M phosphate buffer at pH 7.5 adjusted with 6N NaOH solution.

1.0 mg (0.76 μ mol) of polypeptide 1g is dissolved in the mixture (764 μ L, 1 mM), placed under argon and then stirred at 37°C. The reaction leads exclusively to formation of the cyclic polypeptide 3g (SEQ ID NO: 12).

Polypeptide 3g: cyclo(CHHLEPGG); C₃₅H₄₉N₁₂O₁₀S MALDI-TOF analysis [M+H]⁺ calculated 831.1 observed 831.1.

Example 10: oxidation of polypeptides 1c, 1d, 1e and 1f to dithiazepanes (SEQ ID NO: 13, 14, 15 and 16)

Polypeptides 1c, 1d, 1e and 1f are as obtained in Example 7. These polypeptides are oxidized according to the following general diagram :



= peptide-dithiazepane

Each polypeptide is cleaved from the solid support by the action of TFA/DMS/TiS/H₂O solution (92.5/2.5/2.5/2.5; v/v). The polypeptide is then
 5 precipitated in a large volume of a diethyl ether/heptane mixture (1/1; v/v) and washed twice using this solution. The crude polypeptide lyophilized after the cleavage step is then dissolved in a 0.1M solution of ammonium bicarbonate previously degassed for 10 min by bubbling with nitrogen (1 mg/mL).

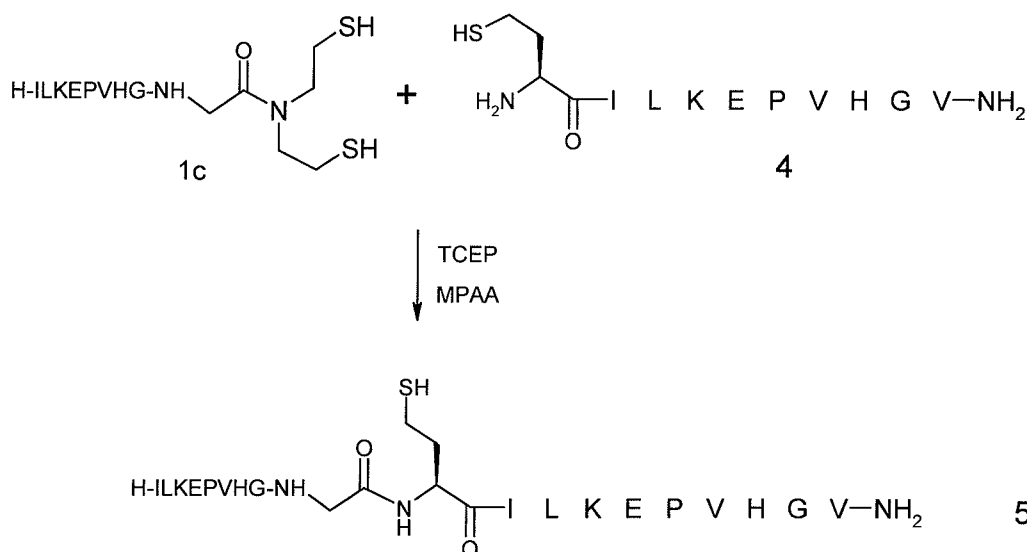
10 The mixture is then stirred vigorously at ambient temperature. The development of the reaction is monitored by MALDI-TOF mass spectrometry until the reduced form of the polypeptide in question has disappeared completely. The polypeptide is finally purified by RP-HPLC (gradient eluent A (H₂O/0.05% TFA)/eluent B (80% acetonitrile/20% H₂O/0.05% TFA): 0 to 10%
 15 in 10 min then 10% to 25% in 25 min), then frozen and lyophilized.

The following table summarizes the results obtained (MALDI-TOF analysis).

Polypeptide	m/z [M+H] ⁺ _{calc.}	m/z [M+H] ⁺ _{obs.}	Final yield (%)
1c	1066.6	1066.6	17
1d	1080.6	1080.6	13
1e	1108.6	1108.6	23
1f	1172.6	1172.6	20

Example 11: ligation between polypeptide 1c and polypeptide 4

20 Polypeptide 1c (SEQ ID NO: 2) is ligated to polypeptide 4 (SEQ ID NO: 17), which is identical to polypeptide 2 except that the N-terminal cysteine is replaced with a homocysteine. This reaction makes it possible to obtain polypeptide 5 (SEQ ID NO: 18). The reaction diagram is as follows:



33.6 mg of MPAA (0.2 mmol, 200 mM) and 57.4 mg of TCEP (0.2 mmol, 200 mM) are dissolved in 1 mL of 0.1 M phosphate buffer (pH adjusted to 7.35). 6.15 mg of polypeptide 1c (4.4 μmol , 7 mM) and 9.35 mg of polypeptide 4 (H-homoCysILKEPVG-NH₂) (6.55 μmol , 10.5 mM) are dissolved in the mixture (624 μL). The mixture is placed under argon and then stirred at 37°C. The product is then purified by RP-HPLC to give 3.3 mg of polypeptide 5 (29%). C₉₁H₁₅₂N₂₆O₂₃S. MALDI-TOF MS analysis (monoisotopic) [M+H]⁺ 2010.12 calculated, 2009.5 found.

Example 12: synthesis of polypeptide 6 (SEQ ID NO: 19)

Polypeptide 6 has the following sequence:



The resin described in Example 5 (0.5 mmol, 0.175 mmol/g) is conditioned in dichloromethane. Fmoc-Lys(Boc)-OH (2.342 g, 5 mmol) is dissolved in dichloromethane and a few drops of DMF to aid solubilization, and then added to the resin. PyBrop (2.331 g, 5 mmol) is dissolved in a minimum amount of dichloromethane and then added to the resin. DIEA (2.613 mL, 15 mmol) is then added to the resin and coupling takes 2h. The

resin is then washed for 3 x 2 minutes with dichloromethane. The resin is then treated with 10% Ac₂O/5% DiEA/dichloromethane (10 mL, 2 min) then (10 mL, 20 min). The resin is then washed for 5 x 2 minutes with dichloromethane.

5 Polypeptide 6 is assembled on a portion of the preceding resin (0.25 mmol, 0.175 mmol/g) with a peptide synthesizer (CEM μ Waves, Saclay, France), using the Fmoc/*tert*-butyl strategy. Coupling is carried out with the amino acids (0.2 M, 4 eq), the activator HBTU (0.5 M, 3.6 eq) and the base DIEA (2 M, 8 eq). The final deprotection and cleavage of the
10 peptide from the resin are carried out with TFA/TIS/DMS/thioanisole/H₂O (90/2.5/2.5/2.5/2.5 by volume, 25 mL) for 2.5 h. The peptide is precipitated in cold diethyl ether/heptane mixture (1/1 by volume), dissolved in a minimum amount of water and lyophilized. 288 mg of crude peptide is obtained (yield=32%). C₁₂₀H₂₁₆N₃₆O₃₁S₄ LC-MS [M+H]⁺ calculated (average mass)
15 2788.5; observed 2788.1.

A portion of polypeptide 6 is then oxidized before purification. For this, polypeptide 6 (49.8 mg) is dissolved in AcOH/water 4/1 (2 mL). It is added dropwise to a solution of iodine in AcOH/water 4/1 (25 mL, "10 eq"). After stirring for 10 minutes, the reaction mixture is transferred to a separating
20 funnel containing water (60 mL). 3 extractions with ether are carried out (3 x 60 mL). The aqueous phase is frozen and lyophilized to give 44.1 mg of crude peptide.

After purification by RP-HPLC (column: Atlantis dC18 OBD 5 μ m, 19 x 100 mm, 210-300 nm, buffer A 100% water containing 0.05% TFA, buffer B
25 CH₃CN/water 4/1 containing 0.05% TFA, gradient: 20 to 40% of buffer B in 40 min, flow rate 25 mL/min), 7.2 mg of pure peptide is obtained (yield=14.5%) C₁₂₀H₂₁₄N₃₆O₃₁S₄ LC-MS [M+H]⁺ calculated (average mass) 2786.52; observed 2786.33.

30 Example 13: synthesis of polypeptide 7 (SEQ ID NO: 20)

Polypeptide 7 has the following sequence:



The resin described in Example 5 (0.5 mmol, 0.175 mmol/g) is conditioned in dichloromethane. Fmoc-Tyr-OH (2.298 g, 5 mmol) is dissolved in dichloromethane (<5 mL) and a few drops of DMF to aid solubilization, then added to the resin. PyBrop (2.331 g, 5 mmol) is dissolved in a minimum amount of DCM and then added to the resin. DIEA (2.614 mL, 15 mmol) is then added to the resin and coupling takes 2 h. The resin is then washed for 4 x 2 minutes with dichloromethane. The resin is then treated with 10% Ac₂O/5% DIEA/DCM (10 mL, 2 min) then (10 mL, 20 min). The resin is then washed for 5 x 2 minutes with dichloromethane.

Polypeptide 7 is assembled on the preceding resin (0.5 mmol, 0.175 mmol/g) with a peptide synthesizer (CEM μ Waves, Saclay, France), using the Fmoc/*tert*-butyl strategy. Coupling is carried out with the amino acids (0.2 M, 4 eq), the activator HBTU (0.5 M, 3.6 eq) and the base DIEA (2 M, 8 eq). The washing solvent (DMF) and the solvent of Fmoc-Met-OH contain 1% of thioanisole for maximum avoidance of oxidation of the methionine of the sequence.

The resin is separated into 2 after the glutamine in position 2 (0.25 mmol) in order to couple the Boc-L-Thz-OH manually. To do this, the resin is washed for 4 x 2 minutes with DMF, weighed in DMF and divided into 2. HBTU (379.3 mg, 1 mmol) is dissolved in DMF (1100 μ L). HOBt (135 mg, 1 mmol) is dissolved in DMF (500 μ L) and added to the HBTU. Boc-L-Thz-OH (233.29 mg, 1 mmol) is dissolved in DMF (500 μ L) and added to the HBTU/HOBt mixture. DIEA (522.7 μ L, 3 mmol) is then added to the mixture. It is stirred for 1 minute, then the mixture is added to the resin and coupling takes 45 minutes. The resin is then washed for 4 x 2 minutes with DMF, 4 x 2 minutes with dichloromethane and then 3 x 2 minutes with Et₂O and dried.

The final deprotection and cleavage of the peptide from the resin are carried out with TFA/TIS/DMS/thioanisole/H₂O (90/2.5/2.5/2.5/2.5 by volume, 25 mL) for 2.5 h. The peptide is precipitated in a cold diethyl ether/heptane mixture (1/1 by volume), dissolved in a minimum amount of water and lyophilized. 369 mg of crude peptide is obtained (yield=37.6%). C₁₅₃H₂₂₃N₄₁O₄₄S₄ MALDI-TOF [M+H]⁺ calculated (monoisotopic resolution) 3467.54; observed 3466.0.

A portion of polypeptide 7 is then oxidized before purification. For this, fragment 2 (51.8 mg) is dissolved in CH₃CN (2.38 mL) and then 0.2 M phosphate buffer pH=7.3 (9.50 mL) is added. It is added dropwise to a solution of 10 mM diamide in water (1.32 mL, 1 eq). After stirring for 15 minutes, the reaction mixture is diluted with buffer A (1.8 mL) and injected in

RP-HPLC (column: Atlantis dC18 OBD 5 μ m, 19 x 100 mm, 210-300 nm, buffer A 100% water containing 0.05% TFA, buffer B CH₃CN/water 4/1 containing 0.05% TFA, gradient: 25 to 45% of buffer B in 40 min, flow rate 25 mL/min); 11.2 mg of pure peptide is obtained (yield=21.6%)
 5 C₁₅₃H₂₂₁N₄₁O₄₄S₄ LC-MS [M+H]⁺ calculated (average mass) 3467.97; 3467.38.

Example 14: synthesis of polypeptide 8 (SEQ ID NO: 21)

Polypeptide 8 has the following sequence:

10



Polypeptide 8 is assembled on Novasyn TGR resin (0.5 mmol, 0.25 mmol/g) with a peptide synthesizer (CEM μ Waves, Saclay, France),
 15 using the Fmoc/*tert*-butyl strategy. Coupling is carried out with the amino acids (0.2 M, 4 eq), the activator HBTU (0.5 M, 3.6 eq) and the base DIEA (2 M, 8 eq). The final deprotection and cleavage of the peptide from the resin are carried out with TFA/EDT/H₂O/TIS (94/2.5/2.5/1 by volume, 30 mL) for 2.5 h. The peptide is precipitated in a cold diethyl ether/heptane mixture (1/1
 20 by volume), dissolved in a minimum amount of water and lyophilized. After RP-HPLC purification (Vydac C18 column 50 cm x 2 cm, 280 nm, buffer A 100% water containing 0.05% TFA, buffer B CH₃CN/water 4/1 containing 0.05% TFA, gradient: 0 to 20% of buffer B in 10 min then 20 to 50% of buffer B in 60 min, flow rate 30 mL/min), 272 mg of pure peptide is obtained
 25 (yield=13%) C₁₅₈H₂₃₉N₄₇O₅₂S₄ MALDI-TOF [M+H]⁺ calculated (monoisotopic resolution) 3755.6; observed 3755.7.

Example 15: ligation of polypeptide 7 and of polypeptide 8 (in glove box) to obtain polypeptide 7-8 (SEQ ID NO: 22)

30 MPAA (33.70 mg) and TCEP.HCl (57.30 mg) are dissolved in 0.1 M phosphate buffer pH=7.3 containing 4 M guanidine HCl (1 mL). The solution pH is adjusted to 7.2 with 5N soda (200 μ L). The polypeptides 7 (8.5 mg) and 8 (18.25 mg, 2 eq) are weighed in the same tube and dissolved with the previous solution (309 μ L). The reaction mixture is placed in a bath at 37°C.
 35 After 24 h, the reaction mixture is diluted with the same solution (300 μ L).

25 h later, 56 mM O-methylhydroxylamine in 0.1 M acetate buffer at pH=3.93 (1.52 mL) is added. The pH of the reaction mixture is adjusted to pH=4.15 with acetic acid (35 μ L). After 20 h at 37°C, the reaction mixture is taken out of the glove box. MPAA is extracted with Et₂O (3 x 6 mL). The reaction mixture is treated for 20 minutes with TCEP.HCl (28 mg) before purification by RP-HPLC (Uptisphere 5C4 column 27.5 cm x 1 cm, 215 nm, buffer A 100% water containing 0.05% TFA, buffer B CH₃CN/water 4/1 containing 0.05% TFA, gradient: 0 to 20% of buffer B in 3 min then 20 to 50% of buffer B in 57 min, flow rate 6 mL/min). 4.4 mg of pure polypeptide 7-8 is obtained (yield=25.4%) C₃₀₆H₄₅₁N₈₇O₉₆S₆ MALDI-TOF [M+H]⁺ calculated (average mass) 7077.8; observed 7078.5.

Example 16: ligation of polypeptide 6 and of polypeptide 7-8 (in glove box) to obtain polypeptide 6-7-8 (SEQ ID NO: 23)

MPAA (33.74 mg) and TCEP.HCl (57.54 mg) are dissolved in 0.1 M of phosphate buffer at pH=7.3 containing 4 M of guanidine HCl (1 mL). The solution pH is adjusted to 7.2 with 5 N soda (220 μ L). The polypeptides 7-8 (3.85 mg) and 6 (2.89 mg, 1.7 eq) are weighed in the same tube and dissolved with the aforementioned solution (115 μ L). The reaction mixture is placed in a bath at 37°C.

After 24 h, formation of the ligation product is observed, namely polypeptide 6-7-8 of sequence: H-IRNCIIIGKGRSYKGTVSITKSG IKCQPWSSMIPHEHSFLPSSYRGKDLQENYCRNPRGEEGGPWCFSTSNPEV RYEVCDIPQCSEV-NH₂

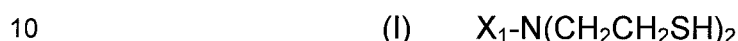
C₄₁₈H₆₄₈N₁₂₂O₁₂₇S₇ MALDI-TOF [M+H]⁺ calculated (average mass) 9640.01; observed 9640.1.

CLAIMS

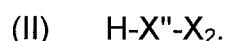
1. Method for manufacturing a polypeptide of formula:



X_1 and X_2 each representing a peptide fragment, and X'' representing an amino acid residue comprising a thiol function, said method comprising at least one step of ligation reaction between a polypeptide of formula:

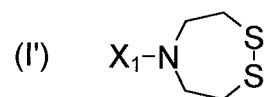


and a polypeptide of formula:



2. Method according to claim 1, in which the ligation reaction is carried out by bringing a polypeptide of formula:

15

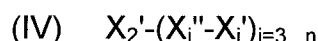


into contact with the polypeptide of formula (II), in the presence of at least one compound that reduces the disulphide bonds, the polypeptide of formula (I') being reduced *in situ* to the polypeptide of formula (I) for the ligation reaction.

20

3. Method according to claim 1 or 2, in which X_2 represents a peptide fragment of formula

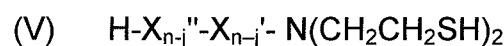
25



n being an integer greater than or equal to 3, each X_i'' , for i an integer comprised between 3 and n , representing an amino acid residue bearing a thiol function, and each X_i' , for i an integer comprised between 2 and n , representing a peptide fragment; said method comprising, before the step of ligation reaction between the polypeptide of formula (I) and the polypeptide of formula (II), a succession of $n-2$ steps of ligation reaction, the j^{th} step of ligation reaction, for j an integer comprised between 1 and $n-2$, being a ligation reaction between a polypeptide of formula:

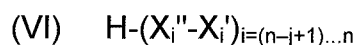
30

35

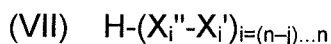


in which the amine function and/or the thiol function of the residue X_{n-j} is protected

and a polypeptide of formula:

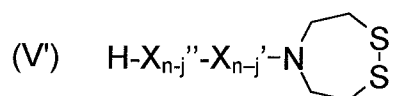


to form a polypeptide of formula:

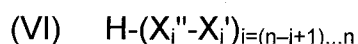


the polypeptide of formula (VII) undergoing deprotection of the thiol function of the residue X_{n-j} at the end of the ligation reaction.

4. Method according to claim 3, in which one or more of the $n-2$ steps of ligation reaction between the polypeptide of formula (V) and the polypeptide of formula (VI) is carried out by bringing a polypeptide of formula:

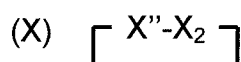


into contact with the polypeptide of formula:



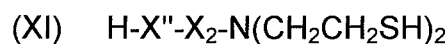
j being an integer comprised between 1 and $n-2$, in the presence of at least one compound that reduces the disulphide bonds.

5. Method for manufacturing a cyclic polypeptide of formula:



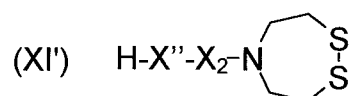
X_2 representing a peptide fragment, and X'' representing an amino acid residue comprising a thiol function,

said method comprising at least one step of ligation reaction of a polypeptide of formula:



with itself.

6. Method according to claim 5, in which the ligation reaction is carried out by bringing a polypeptide of formula:

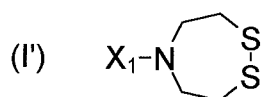


into contact with at least one compound that reduces the disulphide bonds, the polypeptide of formula (XI') being reduced *in situ* to the polypeptide of formula (XI) for the ligation reaction.

- 5 **7.** Method according to one of claims 1 to 6, in which the ligation reaction or ligation reactions are carried out in an aqueous medium, preferably at a pH comprised between 6.5 and 8.5, more particularly preferably between 7 and 8, and ideally of approximately 7.5.

- 10
8. Method according to one of claims 1 to 7, in which the ligation reaction or ligation reactions are carried out in the presence of at least one compound that reduces the disulphide bonds, selected from tris(2-carboxyethyl)phosphine, 4-mercaptophenylacetic acid, dithiothreitol, benzyl mercaptan and mixtures thereof.
- 15

9. Polypeptide of formula:
(I) $X_1-N(CH_2CH_2SH)_2$
or of formula:



in which X₁ represents a peptide fragment and the group -N(CH₂CH₂SH)₂ or

is bound to the C=O termination of the amino acid residue of peptide fragment X_1 that is in C-terminal position.

- 30 **10.** Polypeptide according to claim 9, in which X₁ comprises between 2 and 300 amino acid residues, preferably between 5 and 100 amino acid residues, more particularly preferably between 8 and 50 amino acid residues.

- 11.** Method for manufacturing a polypeptide of formula:
(I) $X_1-N(CH_2CH_2SH)_2$

X_1 representing a peptide fragment and the $-N(CH_2CH_2SH)_2$ group being bound to the $C=O$ termination of the amino acid residue of peptide fragment X_1 that is in C-terminal position, comprising at least one step of peptide synthesis and one step of C-terminal functionalization.

- 12.** Method according to claim 11, in which the step of peptide synthesis precedes the step of functionalization; the step of peptide synthesis supplies a polypeptide of formula:



preferably comprising protective groups on its amine and carboxylic functions, with the exception of its C-terminal carboxylic function; and the step of functionalization comprises:

- reaction of the polypeptide of formula (IX) with the amine compound of formula:



in which G_1 represents a protective group, said protective group preferably forming a thioether, thioester or disulphide function, and more particularly preferably being the triphenylmethyl group, in the liquid phase, to form the polypeptide of formula (I);

- optionally deprotection of the polypeptide of formula (I).

- 13.** Polymer resin support for solid-phase synthesis of polypeptides, comprising a main skeleton and $NH-(CH_2CH_2-S-Trt-)_2$ functional groups or $NH-(CH_2CH_2-S-Trt-CO-NH-)_2$ functional groups, where Trt represents a triphenylmethyl group optionally substituted with one or more substituents, in particular selected from the substituents chlorine, methoxy, methyl, fluorine and cyano; in which the $NH-(CH_2CH_2-S-Trt-)_2$ functional groups are bound to the main skeleton by the two triphenylmethyl groups, or the $NH-(CH_2CH_2-S-Trt-CO-NH-)_2$ functional groups are bound to the main skeleton by the two amine groups.

- 14.** Polymer resin support for solid-phase synthesis of polypeptides, comprising a main skeleton and $G_2-AA-N-(CH_2CH_2-S-Trt-)_2$ functional groups or $G_2-AA-N-(CH_2CH_2-S-Trt-CO-NH-)_2$ functional groups, where Trt represents a triphenylmethyl group

optionally substituted with one or more substituents, in particular selected from the substituents chlorine, methoxy, methyl, fluorine and cyano; AA represents an amino acid residue optionally bearing one or more protective groups; G₂ represents a hydrogen atom or a group protecting the amine function; in which the G₂-AA-N(CH₂CH₂-S-Trt-)₂ functional groups are bound to the main skeleton by the two triphenylmethyl groups or the G₂-AA-N-(CH₂CH₂-S-Trt-CO-NH-)₂ functional groups are bound to the main skeleton by the two amine groups.

15. Polymer resin support according to claim 13 or 14, in which the main skeleton is selected from the polystyrene, polyacrylamide, polyethylene glycol, cellulose, polyethylene, polyester, latex, polyamide, polydimethylacrylamide, polyethylene glycol-polystyrene copolymer, polyethylene glycol-polyacrylamide copolymer skeletons and derivatives thereof.

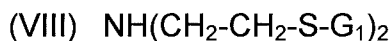
16. Method for manufacturing a polymer resin support for solid-phase synthesis of polypeptides, comprising:

- supplying a polymer resin;
- functionalization of the polymer resin by reaction with the amine compound of formula:



17. Method according to claim 16, comprising, prior to the step of functionalization of the polymer resin:

- supplying an amine compound of formula:



in which G₁ represents a protective group, said protective group preferably forming a thioether, thioester or disulphide function, and more particularly preferably being the triphenylmethyl group;

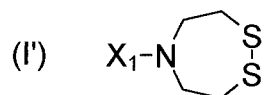
- deprotection of this amine compound to obtain the amine compound of formula (VIII').

18. Method according to claim 11, in which:

- the step of functionalization precedes the step of peptide synthesis;
- the step of functionalization comprises:
 - coupling an amino acid to a polymer resin support according to claim 13 or 15, to supply a primer support; or
 - supplying a primer support which is a polymer resin support according to claim 14;
- the step of peptide synthesis comprises a succession of couplings of amino acids on the primer support.

19. Method according to claim 18, in which coupling of an amino acid to the polymer resin support comprises bringing the polymer resin support into contact with an amino acid halide or with an amino acid and an activating agent, preferably selected from PyBOP, BOP, PyBROP, more particularly preferably PyBROP.

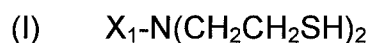
20. Method for manufacturing a polypeptide of formula:



in which X_1 represents a peptide fragment and the



group is bound to the C=O termination of the amino acid residue of peptide fragment X_1 that is in C-terminal position, comprising a step of oxidation of a polypeptide of formula:



preferably in contact with the air, or in the presence of I_2 or of diamide, and in a buffer, said oxidation step preferably being preceded by a step of manufacture of the polypeptide of formula (I) according to the method of claims 11, 12, 18 or 19.

21. Method according to one of claims 1 to 8, comprising a step of manufacture of the polypeptide of formula (I) and/or (V) or (XI) according to the method of claims 11, 12, 18 or 19 or a step of

manufacture of the polypeptide of formula (I') and/or (V') or (XI') according to the method of claim 20.

5 **22.** Method for manufacturing a pharmaceutical composition comprising:

- manufacture of a polypeptide according to the method of one of claims 1 to 8 or 21, and
- formulating this polypeptide with one or more pharmaceutically acceptable adjuvants.

10

23. Method for manufacturing a diagnostic device comprising:

- manufacture of a polypeptide according to the method of one of claims 1 to 8 or 21, and
- formulating this polypeptide in a form suitable for diagnostic use.

15