Quick-acting insulin formulation including a substituted anionic compound

[0001] The present invention relates to a rapid-acting insulin formulation.

[0002] Since the production of insulin by genetic engineering, at the start of the 1980s, diabetic patients have benefited from human insulin for their treatment. This product has greatly improved this therapy, since the immunological risks associated with the use of non-human insulin, in particular pig insulin, are eliminated. However, subcutaneously-injected human insulin has a hypoglycemiant effect only after 60 minutes, which means that diabetic patients treated with human insulin must take the injection 30 minutes before a meal.

[0003] One of the problems to be solved for improving the health and comfort of diabetic patients is that of providing them with insulin formulations which afford a faster hypoglycemiant response than that of human insulin, if possible a response approaching the physiological response of a healthy person. The secretion of endogenous insulin in a healthy individual is immediately triggered by the increase in glycemia. The object is to minimize the delay between the injection of insulin and the start of the meal.

[0004] At the present time, it is accepted that the provision of such formulations is useful in order for the patient to receive the best possible health care.

[0005] Genetic engineering has made it possible to afford a response with the development of rapid insulin analogs. These insulins are modified on one or two amino acids so as to be more rapidly absorbed into the blood compartment after a subcutaneous injection. These insulins lispro (Humalog®, Lilly), aspart (Novolog®, Novo) and glulisine (Apidra®, Sanofi Aventis) are stable insulin solutions with a faster hypoglycemiant response than that of human insulin. Consequently, patients treated with these rapid insulin analogs can take an insulin injection only 15 minutes before a meal.

[0006] The principle of rapid insulin analogs is to form hexamers at a concentration of 100 IU/mL to ensure the stability of the insulin in the commercial product while at the same time promoting very rapid dissociation of these hexamers into monomers after subcutaneous injection so as to obtain rapid action.

[0007] Human insulin as formulated in its commercial form does not make it possible to obtain a hypoglycemiant response close in kinetic terms to the physiological response generated by the start of a meal (increase in glycemia), since, at the working concentration (100 IU/mL), in the presence of zinc and other excipients such as phenol or *m*-cresol, it assembles to form a hexamer, whereas it is active in monomer and dimer form. Human insulin is prepared in the form of hexamers so as to be stable for up to 2 years at 4°C, since, in the form of monomers, it has a very high

propensity to aggregate and then to fibrillate, which makes it lose its activity. Furthermore, in this aggregated form, it presents an immunological risk to the patient.

[0008] The dissociation of the hexamers into dimers and of the dimers into monomers delay its action by close to 20 minutes when compared with a rapid insulin analog (Brange J., et al., Advanced Drug Delivery Review, 35, 1999, 307-335).

[0009] In addition, the kinetics of passage of the insulin analogs into the blood and their glycemia reduction kinetics are not optimal, and there is a real need for a formulation which has an even shorter action time in order to come close to the kinetics of endogenous insulin secretion in healthy individuals.

[00010] The company Biodel has proposed a solution to this problem with a human insulin formulation comprising EDTA and citric acid as described in patent application US 200839365. The capacity of EDTA to complex zinc atoms and the interactions of citric acid with the cationic regions present at the surface of insulin are described as destabilizing the hexameric form of insulin and thus as reducing its action time.

[00011] However, such a formulation especially has the drawback of disassociating the hexameric form of insulin, which is the only stable form capable of meeting the stability requirements of the pharmaceutical regulations.

[00012] PCT patent application WO 2010/122385 in the name of the Applicant is also known, describing human insulin or insulin analog formulations that can solve the various problems mentioned above via the addition of a substituted polysaccharide comprising carboxyl groups.

[00013] However, the requirements entailed by the chronic and intensive use or even the pediatric use of such formulations lead a person skilled in the art to seek to use excipients whose molar mass and size are as small as possible in order to facilitate their elimination.

[00014] The polysaccharides described in patent applications WO 2010/122385A1 and US 2012/094902A1 as excipients are compounds consisting of chains whose lengths are statistically variable and which are very rich in possible sites of interaction with protein active principles. This richness might induce a lack of specificity in terms of interaction, and a smaller and better defined molecule might make it possible to be more specific in this respect.

[00015] In addition, a molecule with a well-defined backbone is generally more easily traceable (for example MS/MS) in biological media during pharmacokinetic or ADME (administration, distribution, metabolism, elimination) experiments when compared with a polymer which generally gives a very diffuse and noisy signal in mass spectrometry.

[00016] Conversely, it is not excluded that a well-defined and shorter molecule might have a deficit of possible sites of interaction with protein active principles.

Specifically, on account of their reduced size, they do not have the same properties as polymers of polysaccharide type since there is loss of the polymer effect, as is demonstrated in the comparative examples of the experimental section; see especially the tests of insulin dissolution at the isoelectric point and the tests of interaction with a model protein such as albumin.

[00017] Despite these discouraging results, the Applicant has succeeded in developing formulations that are capable of accelerating insulin by using a substituted anionic compound in combination with a polyanionic compound.

[00018] Furthermore, as in the case of the use of polysaccharides, the hexameric nature of insulin is not affected, and thus the stability of the formulations is not affected, as is moreover confirmed by the examples of state of association of human insulin and insulin analog via circular dichroism in the presence of a substituted anionic compound according to the invention.

[00019] The present invention makes it possible to solve the various problems outlined above since it makes it possible especially to prepare a human insulin or insulin analog formulation, which is capable, after administration, of accelerating the passage of the human insulin or of analogs thereof into the blood and of more quickly reducing glycemia when compared with the corresponding commercial insulin products.

[00020] The invention consists of a composition, in aqueous solution, comprising insulin in hexameric form, at least one substituted anionic compound and a non-polymeric polyanionic compound.

[00021] The term "substituted anionic compound" means compounds consisting of a saccharide backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from the group consisting of hexoses, in cyclic form or in open reduced form, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable.

[00022] In one embodiment, the insulin is in hexameric form.

[00023] In one embodiment, the insulin is human insulin.

[00024] The term "human insulin" means an insulin obtained by synthesis or recombination, whose peptide sequence is the sequence of human insulin, including the allelic variations and homologs.

[00025] In one embodiment, the insulin is a recombinant human insulin as described in the European Pharmacopea and the American Pharmacopea.

[00026] In one embodiment, the insulin is an insulin analog.

[00027] The term "insulin analog" means a recombinant insulin whose primary sequence contains at least one modification relative to the primary sequence of human insulin.

[00028] In one embodiment, the insulin analog is chosen from the group consisting of the insulin lispro (Humalog®), the insulin aspart (Novolog®, Novorapid®) and the insulin glulisine (Apidra®).

[00029] In one embodiment, the insulin analog is the insulin lispro (Humalog®).

[00030] In one embodiment, the insulin analog is the insulin aspart (Novolog®, Novorapid®).

[00031] In one embodiment, the insulin analog is the insulin glulisine (Apidra®).

[00032] In one embodiment, the substituted anionic compound is chosen from substituted anionic compounds, in isolated form or as a mixture, consisting of a backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from the group consisting of hexoses, in cyclic form or in open reduced form, characterized in that they are substituted with:

a) at least one substituent of general formula I:

$$-[R_1]_a-[AA]_m \qquad \text{Formula I}$$

- the substituents being identical or different when there are at least two substituents, in which:
- the radical -[AA] denotes an amino acid residue,
- the radical -R_1- being:
  - either a bond and then a = 0 and the amino acid residue -[AA] is directly linked to the backbone via a function G,
  - or a C2 to C15 carbon-based chain, and then a = 1, optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function before the reaction with the amino acid, said chain forming with the amino acid residue -[AA] an amide function, and is attached to the backbone by means of a function F resulting from a reaction between a

hydroxyl function borne by the backbone and a function or substituent borne by the precursor of the radical -R_1-,

- F is a function chosen from ether, ester and carbamate functions,
- G is a carbamate function,
- m is equal to 1 or 2,
- the degree of substitution of the saccharide units, j, in $-[R_1]_a-[AA]_m$ being strictly greater than 0 and less than or equal to 6, $0 < j \leq 6$

b) and, optionally, one or more substituents $-R'_1$,

- the substituent -R'_1 being a C2 to C15 carbon-based chain, which is optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function in the form of an alkali metal cation salt, said chain being linked to the backbone via a function F' resulting from a reaction between a hydroxyl function borne by the backbone and a function or substituent borne by the precursor of the substituent -R'_1,
- F' is an ether, ester or carbamate function,
- the degree of substitution of the saccharide units, i, in -R'_1, being between 0 and 6-j, $0 \leq i \leq 6-j$, and
- F and F' are identical or different,
- F and G are identical or different,
- $i+j \leq 6$,
- -R'_1 is identical to or different from $-R_1-$,
- the free salifiable acid functions borne by the substituent -R'_1 are in the form of alkali metal cation salts,
- said glycoside bonds, which may be identical or different, being chosen from the group consisting of glycoside bonds of (1,1), (1,2), (1,3), (1,4) or (1,6) type, in an alpha or beta geometry.

[00033] In one embodiment, the substituted anionic compound, in isolated form or as a mixture, is chosen from substituted anionic compounds consisting of a saccharide backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from hexoses, in cyclic form or in open reduced form, characterized

a) in that they are randomly substituted with:

- at least one substituent of general formula I:

$$-[R_1]_a-[AA]_m \qquad \text{Formula I}$$

- the substituents being identical or different when there are at least two substituents, in which:
- the radical –[AA]– denotes an amino acid residue, said amino acid being chosen from the group consisting of phenylalanine, alpha-methylphenylalanine, 3,4-dihydroxyphenylalanine, tyrosine, alpha-methyltyrosine, O-methyltyrosine, alpha-phenylglycine, 4-hydroxyphenylglycine and 3,5-dihydroxyphenylglycine, and the alkali metal cation salts thereof, said derivatives being of L or D absolute configuration, -[AA] is attached to the backbone of the molecule via a linker arm $–R_1–$ or directly linked to the backbone via a function G,
- $–R_1–$ being:
  - either a bond G, and then a = 0,
  - or a C2 to C15 carbon-based chain, and then a = 1, which is optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and bearing at least one acid function before the reaction with the amino acid, said chain forming with the amino acid residue -[AA] an amide bond, and is attached to the saccharide backbone via a function F resulting from a reaction between a hydroxyl function borne by the backbone and a function borne by the precursor of R_1,
- F is an ether, ester or carbamate function,
- G is a carbamate function,
- m is equal to 1 or 2,
- the degree of substitution, j, in $–[R_1]_a–[AA]_m$ being strictly greater than 0 and less than or equal to 6, $0 < j \leq 6$,

and, optionally,

- one or more substituents $–R'_1$
- $-R'_1$ being a C2 to C15 carbon-based chain, which is optionally substituted and/or comprising at least one heteroatom (such as O, N and S) and bearing at least one acid function in the form of an alkali metal cation salt, said chain being attached to the saccharide backbone via a function F' resulting from a reaction between a hydroxyl function borne by the backbone and a function borne by the precursor of $-R'_1$,
- F' is an ether, ester or carbamate function,
- the degree of substitution, i, in $-R'_1$, being between 0 and 6-j, $0 \leq i \leq 6-j$, and

- -R'$_1$- is identical to or different from –R_1,
- F and F' are identical or different,
- F' and G are identical or different,
- the free salifiable acid functions are in the form of alkali metal cation salts,

b) said glycoside bonds, which may be identical or different, being chosen from the group consisting of glycoside bonds of (1,1), (1,2), (1,3), (1,4) or (1,6) type, in an alpha or beta geometry,

c) i +j ≤ 6.

[00034] In one embodiment, m is equal to 1.

[00035] In one embodiment, -R_1 and -R'1, which may be identical or different, are a C2 to C8 carbon-based chain.

[00036] In one embodiment, -R_1 and -R'1, which may be identical or different, are a C2 to C4 carbon-based chain.

[00037] i and j are statistical degrees of substitution and represent the mean number of substituents per saccharide unit. Since each saccharide unit bears several hydroxyl functions of different reactivity, the distribution of the substituents on the substituted anionic compounds may be different from one saccharide unit to another within the same polyanionic compound.

[00038] In one embodiment, 0.3 ≤ i.

[00039] In one embodiment, 0.4 ≤ i.

[00040] In one embodiment, i ≤ 3.

[00041] In one embodiment, i ≤ 2.5.

[00042] In one embodiment, 0.3 ≤ j.

[00043] In one embodiment, 0.4 ≤ j.

[00044] In one embodiment, j ≤ 2.

[00045] In one embodiment, j ≤ 1.8.

[00046] In one embodiment, i and j are such that 0 < i + j ≤ 6.

[00047] In one embodiment, 0 < i + j ≤ 5.

[00048] In one embodiment, 0 < i + j ≤ 4.

[00049] In one embodiment, 0 < i + j ≤ 3.

[00050] In one embodiment, 0 < i + j ≤ 2.5.

[00051] In one embodiment, 0 < i + j ≤ 2.

[00052] In one embodiment, 0.5 ≤ i + j ≤ 3.

[00053] In one embodiment, 0.5 ≤ i + j ≤ 2.5.

[00054] In one embodiment, 0.5 ≤ i + j ≤ 2.

[00055] In one embodiment, $0.6 \leq i + j \leq 3.5$.

[00056] In one embodiment, $0.8 \leq i + j \leq 2.5$.

[00057] In one embodiment, $0.7 \leq i + j \leq 2.5$.

[00058] In one embodiment, $0.7 \leq i + j \leq 2$.

[00059] In one embodiment, $1 < i + j \leq 2.5$.

[00060] In one embodiment, $1 < i + j \leq 2$.

[00061] In one embodiment, -R1 and -R'1 are attached to the backbone via an ether bond.

[00062] In one embodiment, when -R1- is a carbon-based chain, it is directly attached to the backbone via an ether bond.

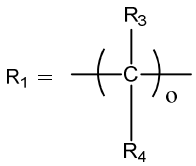
[00063] In one embodiment, when -R1- is a carbon-based chain, it optionally comprises a heteroatom chosen from the group consisting of O, N and S.

[00064] In one embodiment, -R1- forms with the amino acid residue AA an amide bond, and is directly attached to the backbone via an ether function F.

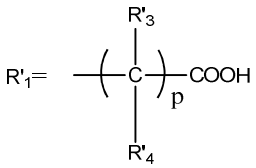
[00065] In one embodiment, -R1- forms with the amino acid residue AA an amide bond, and is directly attached to the backbone via a carbamate function F.

[00066] In one embodiment, -R1- forms with the amino acid residue AA an amide bond, and is directly attached to the backbone via an ester function F.

[00067] In one embodiment, –R1– and –R'1 are chosen from radicals of formulae II and III



Formula II



Formula III,

in which:

- o and p, which may be identical or different, are greater than or equal to 1 and less than or equal to 12, and
- $-R_3$, $-R'_3$, $-R_4$ and $-R'_4$, which may be identical or different, are chosen from the group consisting of a hydrogen atom, a saturated or unsaturated, linear, branched or cyclic C1 to C6 alkyl, a benzyl, a C7 to C10 alkylaryl and optionally comprising heteroatoms chosen from the group consisting of O, N and/or S, or functions chosen from the group consisting of carboxylic acid, amine, alcohol and thiol functions.

[00068] In one embodiment, –R1– before attachment to -AA-, is $–CH_2–COOH$.

[00069] In one embodiment, the substituted anionic compounds according to the invention are characterized in that the radical -R'1 is $–CH_2–COOH$.

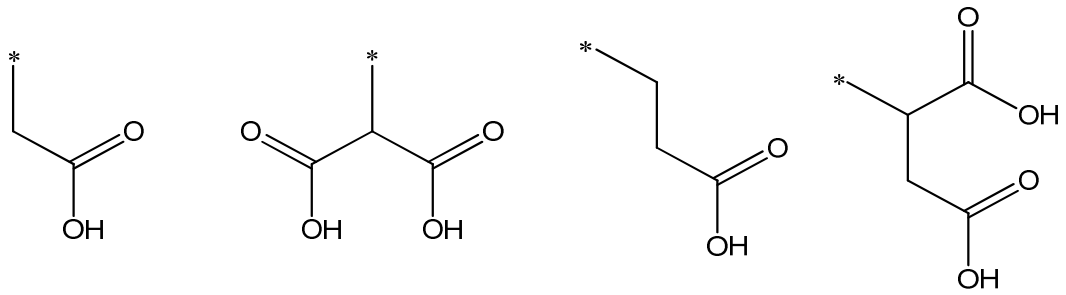
[00070] In one embodiment, -R1- before optional attachment to -AA-, is derived from citric acid.

[00071] In one embodiment, -R1- before optional attachment to -AA-, is derived from malic acid.

[00072] In one embodiment, -R'1 is derived from citric acid.

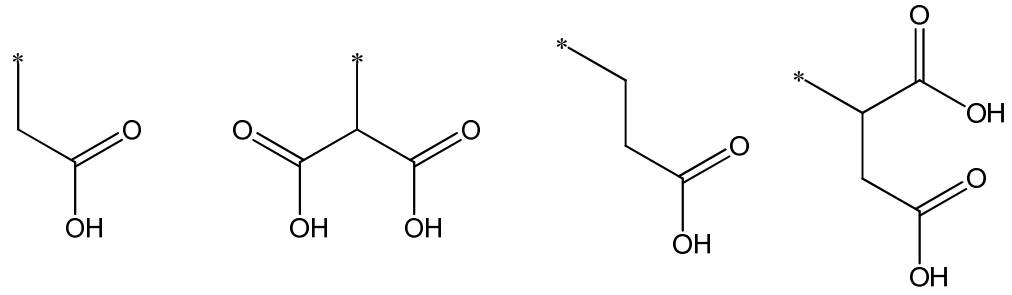
[00073] In one embodiment, -R'1 is derived from malic acid.

[00074] In one embodiment, -R1-, before attachment to -AA-, is chosen from the following groups, in which * represents the site of attachment to F:



or the salts thereof with alkali metal cations chosen from the group consisting of Na^+ and K^+.

[00075] In one embodiment, $-R'_1$ is chosen from the following groups, in which * represents the site of attachment to F:



or the salts thereof with alkali metal cations chosen from the group consisting of Na^+ and K^+.

[00076] In one embodiment, the radical –[AA] is a residue of phenylalanine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00077] In one embodiment, the radical –[AA] is a residue of alpha-methylphenylalanine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00078] In one embodiment, the radical –[AA] is a residue of 3,4-dihydroxyphenylalanine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00079] In one embodiment, the radical –[AA] is a residue of tyrosine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00080] In one embodiment, the radical –[AA] is a residue of alpha-methyltyrosine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00081] In one embodiment, the radical –[AA] is a residue of O-methyltyrosine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00082] In one embodiment, the radical –[AA] is a residue of alpha-phenylglycine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00083] In one embodiment, the radical –[AA] is a residue of 4-hydroxyphenylglycine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00084] In one embodiment, the radical –[AA] is a residue of 3,5-dihydroxyphenylglycine and of alkali metal cation salts thereof of L, D or racemic absolute configuration.

[00085] In one embodiment, the radical -[AA] is an amino acid residue in the form of a racemic mixture.

[00086] In one embodiment, the radical -[AA] is an amino acid residue in the form of isolated isomers of D absolute configuration.

[00087] In one embodiment, the radical -[AA] is an amino acid residue in the form of isolated isomers of L absolute configuration.

[00088] In one embodiment, u is between 1 and 5.

[00089] In one embodiment, u is between 3 and 5.

[00090] In one embodiment, u = 8.

[00091] In one embodiment, u = 7.

[00092] In one embodiment, u = 6.

[00093] In one embodiment, u = 5.

[00094] In one embodiment, u = 4.

[00095] In one embodiment, u = 3.

[00096] In one embodiment, u = 2.

[00097] In one embodiment, u = 1.

[00098] In one embodiment, hexoses are chosen from the group consisting of mannose, glucose, fructose, sorbose, tagatose, psicose, galactose, allose, altrose,

talose, idose, gulose, fucose, fuculose, rhamnose, mannitol, sorbitol and galactitol (dulcitol).

[00099] In one embodiment, the glycoside bonds are of (1,4) or (1,6) type.

[000100] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,1) type.

[000101] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of different saccharide units chosen from hexoses and linked via a glycoside bond of (1,1) type, said saccharide backbone being chosen from the group consisting of trehalose and sucrose.

[000102] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,2) type.

[000103] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,2) type, said saccharide backbone being kojibiose.

[000104] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,3) type.

[000105] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,3) type, said saccharide backbone being chosen from the group consisting of nigeriose and laminaribiose.

[000106] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,4) type.

[000107] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,4) type, said saccharide backbone being chosen from the group consisting of maltose, lactose and cellobiose.

[000108] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,6) type.

[000109] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,6) type, said saccharide backbone being chosen from the group consisting of isomaltose, melibiose and gentiobiose.

[000110] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of identical or different saccharide units chosen from hexoses linked via a glycoside bond of (1,6) type, said saccharide backbone being isomaltose.

[000111] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of saccharide units, one of which is in cyclic form and the other in open reduced form.

[000112] In one embodiment, the substituted anionic compound is chosen from anionic compounds consisting of a saccharide backbone formed from a discrete number u = 2 of saccharide units, one of which is in cyclic form and the other in open reduced form, said saccharide backbone being chosen from the group consisting of maltitol and isomaltitol.

[000113] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is formed from a discrete number $3 \leq u \leq 8$ of identical or different saccharide units.

[000114] In one embodiment, the substituted anionic compound according to the invention is characterized in that at least one of the identical or different saccharide units, of which the saccharide backbone formed from a discrete number $3 \leq u \leq 8$ of saccharide units is composed, is chosen from the group consisting of hexose units linked via identical or different glycoside bonds.

[000115] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units, of which the saccharide backbone formed from a discrete number $3 \leq u \leq 8$ of saccharide units is composed, are chosen from hexoses and linked via at least one glycoside bond of (1,2) type.

[000116] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units, of which

the saccharide backbone formed from a discrete number $3 \leq u \leq 8$ of saccharide units is composed, are chosen from hexoses and linked via at least one glycoside bond of (1,3) type.

[000117] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units, of which the saccharide backbone formed from a discrete number $3 \leq u \leq 8$ of saccharide units is composed, are chosen from hexoses and linked via at least one glycoside bond of (1,4) type.

[000118] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units, of which the saccharide backbone formed from a discrete number $3 \leq u \leq 8$ of saccharide units is composed, are chosen from hexoses and linked via at least one glycoside bond of (1,6) type.

[000119] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is formed from a discrete number $u = 3$ of identical or different saccharide units.

[000120] In one embodiment, the substituted anionic compound according to the invention is characterized in that it comprises at least one saccharide unit chosen from the group consisting of hexoses in cyclic form and at least one saccharide unit chosen from the group consisting of hexoses in open form.

[000121] In one embodiment, the substituted anionic compound according to the invention is characterized in that the three saccharide units are identical.

[000122] In one embodiment, the substituted anionic compound according to the invention is characterized in that two of the three saccharide units are identical.

[000123] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical saccharide units are chosen from hexoses, two of which are in cyclic form and one is in open reduced form, and linked via glycoside bonds of (1,4) type.

[000124] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical saccharide units are chosen from hexoses, two of which are in cyclic form and one is in open reduced form, and linked via glycoside bonds of (1,6) type.

[000125] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and in that the central hexose is linked via a glycoside bond of (1,2) type and via a glycoside bond of (1,4) type.

[000126] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and in that the central hexose is linked via a glycoside bond of (1,3) type and via a glycoside bond of (1,4) type.

[000127] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and in that the central hexose is linked via a glycoside bond of (1,2) type and via a glycoside bond of (1,6) type.

[000128] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and in that the central hexose is linked via a glycoside bond of (1,2) type and via a glycoside bond of (1,3) type.

[000129] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and in that the central hexose is linked via a glycoside bond of (1,4) type and via a glycoside bond of (1,6) type.

[000130] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is erlose.

[000131] In one embodiment, the substituted anionic compound according to the invention is characterized in that the three identical or different saccharide units are hexose units chosen from the group consisting of mannose and glucose.

[000132] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is maltotriose.

[000133] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is isomaltotriose.

[000134] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is formed from a discrete number u = 4 of identical or different saccharide units.

[000135] In one embodiment, the substituted anionic compound according to the invention is characterized in that the four saccharide units are identical.

[000136] In one embodiment, the substituted anionic compound according to the invention is characterized in that three of the four saccharide units are identical.

[000137] In one embodiment, the substituted anionic compound according to the invention is characterized in that the four saccharide units are hexose units chosen from the group consisting of mannose and glucose.

[000138] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is maltotetraose.

[000139] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and in that a terminal hexose is linked via a glycoside bond of (1,2) type and in that the others are linked together via a glycoside bond of (1,6) type.

[000140] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and linked via a glycoside bond of (1,6) type.

[000141] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is formed from a discrete number u = 5 of identical or different saccharide units.

[000142] In one embodiment, the substituted anionic compound according to the invention is characterized in that the five saccharide units are identical.

[000143] In one embodiment, the substituted anionic compound according to the invention is characterized in that the five saccharide units are hexose units chosen from the group consisting of mannose and glucose.

[000144] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and linked via a glycoside bond of (1,4) type.

[000145] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is maltopentaose.

[000146] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is formed from a discrete number u = 6 of identical or different saccharide units.

[000147] In one embodiment, the substituted anionic compound according to the invention is characterized in that the six saccharide units are identical.

[000148] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and linked via a glycoside bond of (1,4) type.

[000149] In one embodiment, the substituted anionic compound according to the invention is characterized in that the six identical or different saccharide units are hexose units chosen from the group consisting of mannose and glucose.

[000150] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is maltohexaose.

[000151] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is formed from a discrete number u = 7 of identical or different saccharide units.

[000152] In one embodiment, the substituted anionic compound according to the invention is characterized in that the seven saccharide units are identical.

[000153] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and linked via a glycoside bond of (1,4) type.

[000154] In one embodiment, the substituted anionic compound according to the invention is characterized in that the seven saccharide units are hexose units chosen from the group consisting of mannose and glucose.

[000155] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is maltoheptaose.

[000156] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is formed from a discrete number u = 8 of identical or different saccharide units.

[000157] In one embodiment, the substituted anionic compound according to the invention is characterized in that the eight saccharide units are identical.

[000158] In one embodiment, the substituted anionic compound according to the invention is characterized in that the identical or different saccharide units are chosen from hexoses and linked via a glycoside bond of (1,4) type.

[000159] In one embodiment, the substituted anionic compound according to the invention is characterized in that the eight saccharide units are hexose units chosen from the group consisting of mannose and glucose.

[000160] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is maltooctaose.

[000161] In one embodiment, the substituted anionic compound comprising a discrete number of saccharide units is a natural compound.

[000162] In one embodiment, the substituted anionic compound comprising a discrete number of saccharide units is a synthetic compound.

[000163] In one embodiment, the substituted anionic compound according to the invention is characterized in that it is obtained by enzymatic degradation of a polysaccharide followed by purification.

[000164] In one embodiment, the substituted anionic compound according to the invention is characterized in that it is obtained by chemical degradation of a polysaccharide followed by purification.

[000165] In one embodiment, the substituted anionic compound according to the invention is characterized in that it is obtained chemically, by covalent coupling of precursors of lower molecular weight.

[000166] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is sophorose.

[000167] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is sucrose.

[000168] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is lactulose.

[000169] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is maltulose.

[000170] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is leucrose.

[000171] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is rutinose.

[000172] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is isomaltulose.

[000173] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is fucosyllactose.

[000174] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is gentianose.

[000175] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is raffinose.

[000176] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is melezitose.

[000177] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is panose.

[000178] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is kestose.

[000179] In one embodiment, the substituted anionic compound according to the invention is characterized in that the saccharide backbone is stachyose.

[000180] In one embodiment, the polyanionic compound is a non-polymeric polyanionic (NPP) compound whose affinity for zinc is less than the affinity of insulin for zinc and whose dissociation constant Kd_{Ca} =[NPP compound]^r [Ca^{2+}]^s/[(NPP compound)^r-(Ca^{2+})^s] is less than or equal to $10^{-1.5}$.

[000181] The dissociation constants (Kd) of the various polyanionic compounds with respect to calcium ions are determined by external calibration using an electrode specific for calcium ions (Mettler-Toledo) and a reference electrode. All the measurements are performed in 150 mM NaCl at pH 7. Only the concentrations of free calcium ions are determined; the calcium ions bound to the polyanionic compound do not induce any electrode potential.

[000182] In one embodiment, the polyanionic compound is chosen from the group consisting of polycarboxylic acids and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

[000183] In one embodiment, the polycarboxylic acid is chosen from the group consisting of citric acid and tartaric acid, and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

[000184] In one embodiment, the polyanionic compound is chosen from the group consisting of polyphosphoric acids and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

[000185] In one embodiment, the polyphosphoric acid is triphosphate and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

[000186] In one embodiment, the polyanionic compound is citric acid and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

[000187] In one embodiment, the polyanionic compound is tartaric acid and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

[000188] In one embodiment, the polyanionic compound is triphosphoric acid and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

[000189] In one embodiment, the polyanionic compound is a compound consisting of a saccharide backbone formed from a discrete number of saccharide units obtained from a disaccharide compound chosen from the group consisting of trehalose, maltose, lactose, sucrose, cellobiose, isomaltose, maltitol and isomaltitol.

[000190] In one embodiment, the polyanionic compound consisting of a saccharide backbone formed from a discrete number of saccharide units is obtained from a compound consisting of a backbone formed from a discrete number of saccharide units chosen from the group consisting of maltotriose, maltotetraose, maltopentaose, maltohexaose, maltoheptaose, maltooctaose and isomaltotriose.

[000191] In one embodiment, the polyanionic compound consisting of a saccharide backbone formed from a discrete number of saccharide units is chosen from the group consisting of carboxymethylmaltotriose, carboxymethylmaltotetraose,

carboxymethylmaltopentaose, carboxymethylmaltohexaose, carboxymethylmaltoheptaose, carboxymethylmaltooctaose and carboxymethylisomaltotriose.

[000192] In one embodiment, the ratio (number of moles of acid functions borne by the polyanionic compound/number of moles of anionic compound) is greater than or equal to 3.

[000193] In one embodiment, the ratio (number of moles of acid functions borne by the polyanionic compound/number of moles of anionic compound) is greater than or equal to 4.

[000194] In one embodiment, the ratio (number of moles of acid functions borne by the polyanionic compound consisting of a saccharide backbone/number of moles of anionic compound) is greater than or equal to 5.

[000195] In one embodiment, the ratio (number of moles of acid functions borne by the polyanionic compound consisting of a saccharide backbone/number of moles of anionic compound) is greater than or equal to 8.

[000196] In one embodiment, the substituted anionic compound/insulin mole ratios are between 0.6 and 75.

[000197] In one embodiment, the mole ratios are between 0.7 and 50.

[000198] In one embodiment, the mole ratios are between 1.4 and 35.

[000199] In one embodiment, the mole ratios are between 1.9 and 30.

[000200] In one embodiment, the mole ratios are between 2.3 and 30.

[000201] In one embodiment, the substituted anionic compound/insulin mole ratio is equal to 8.

[000202] In one embodiment, the substituted anionic compound/insulin mole ratio is equal to 12.

[000203] In one embodiment, the substituted anionic compound/insulin mole ratio is equal to 16.

[000204] In one embodiment, the substituted anionic compound/insulin mass ratios are between 0.5 and 10.

[000205] In one embodiment, the mass ratios are between 0.6 and 7.

[000206] In one embodiment, the mass ratios are between 1.2 and 5.

[000207] In one embodiment, the mass ratios are between 1.6 and 4.

[000208] In one embodiment, the mass ratios are between 2 and 4.

[000209] In one embodiment, the substituted anionic compound/insulin mass ratio is 2.

[000210] In one embodiment, the substituted anionic compound/insulin mass ratio is 3.

[000211] In one embodiment, the substituted anionic compound/insulin mass ratio is 4.

[000212] In one embodiment, the substituted anionic compound/insulin mass ratio is 6.

[000213] In one embodiment, the concentration of substituted anionic compound is between 1.8 and 36 mg/mL.

[000214] In one embodiment, the concentration of substituted anionic compound is between 1.8 and 36.5 mg/mL.

[000215] In one embodiment, the concentration of substituted anionic compound is between 2.1 and 25 mg/mL.

[000216] In one embodiment, the concentration of substituted anionic compound is between 4.2 and 18 mg/mL.

[000217] In one embodiment, the concentration of substituted anionic compound is between 5.6 and 15 mg/mL.

[000218] In one embodiment, the concentration of substituted anionic compound is between 7 and 15 mg/mL.

[000219] In one embodiment, the concentration of substituted anionic compound is 7.3 mg/mL.

[000220] In one embodiment, the concentration of substituted anionic compound is 10.5 mg/mL.

[000221] In one embodiment, the concentration of substituted anionic compound is 14.6 mg/mL.

[000222] In one embodiment, the concentration of substituted anionic compound is 21.9 mg/mL.

[000223] In one embodiment, the concentration of polyanionic compound is between 2 and 150 mM.

[000224] In one embodiment, the concentration of polyanionic compound is between 2 and 100 mM.

[000225] In one embodiment, the concentration of polyanionic compound is between 2 and 75 mM.

[000226] In one embodiment, the concentration of polyanionic compound is between 2 and 50 mM.

[000227] In one embodiment, the concentration of polyanionic compound is between 2 and 30 mM.

[000228] In one embodiment, the concentration of polyanionic compound is between 2 and 20 mM.

[000229] In one embodiment, the concentration of polyanionic compound is between 2 and 10 mM.

[000230] In one embodiment, the concentration of polyanionic compound is between 5 and 150 mM.

[000231] In one embodiment, the concentration of polyanionic compound is between 5 and 100 mM.

[000232] In one embodiment, the concentration of polyanionic compound is between 5 and 75 mM.

[000233] In one embodiment, the concentration of polyanionic compound is between 5 and 50 mM.

[000234] In one embodiment, the concentration of polyanionic compound is between 5 and 30 mM.

[000235] In one embodiment, the concentration of polyanionic compound is between 5 and 20 mM.

[000236] In one embodiment, the concentration of polyanionic compound is between 5 and 10 mM.

[000237] In one embodiment, the concentration of polyanionic compound is between 0.5 and 30 mg/mL.

[000238] In one embodiment, the concentration of polyanionic compound is between 0.5 and 25 mg/mL.

[000239] In one embodiment, the concentration of polyanionic compound is between 0.5 and 10 mg/mL.

[000240] In one embodiment, the concentration of polyanionic compound is between 0.5 and 8 mg/mL.

[000241] In one embodiment, the concentration of polyanionic compound is between 1 and 30 mg/mL.

[000242] In one embodiment, the concentration of polyanionic compound is between 1.5 and 25 mg/mL.

[000243] In one embodiment, the concentration of polyanionic compound is between 2 and 25 mg/mL.

[000244] In one embodiment, the concentration of polyanionic compound is between 2 and 10 mg/mL.

[000245] In one embodiment, the concentration of polyanionic compound is between 2 and 8 mg/mL.

[000246] In one embodiment, the substituted anionic compound is sodium maltotriosemethylcarboxylate modified with sodium phenylalaninate, u = 3, i = 0.65, j = 1.0.

[000247] In one embodiment, the substituted anionic compound is sodium maltotriosemethylcarboxylate modified with sodium phenylalaninate, u = 3, i = 1.0, j = 0.65.

[000248] In one embodiment, the substituted anionic compound is sodium maltotriosemethylcarboxylate modified with sodium phenylalaninate, u = 3, i = 0.46, j = 1.2.

[000249] In one embodiment, the substituted anionic compound is sodium maltotriosemethylcarboxylate modified with sodium phenylalaninate, u = 3, i = 0.35, j = 0.65.

[000250] In one embodiment, the polyanionic compound is sodium maltotriosemethylcarboxylate.

[000251] In one embodiment, the polyanionic compound is sodium citrate.

[000252] In one embodiment, the polyanionic compound is triphosphate in acidic form or in basic form in the form of the sodium salt or the potassium salt.

[000253] In one embodiment, the polyanionic compound is tartrate in acidic form or in basic form in the form of the sodium salt or the potassium salt.

[000254] The invention also relates to an insulin pharmaceutical formulation comprising a composition according to the invention, in which the insulin is in hexameric form.

[000255] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is between 240 and 3000 μM (40 to 500 IU/mL).

[000256] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is between 600 and 3000 μM (100 to 500 IU/mL).

[000257] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is between 600 and 2400 μM (100 to 400 IU/mL).

[000258] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is between 600 and 1800 μM (100 to 300 IU/mL).

[000259] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is between 600 and 1200 µM (100 to 200 IU/mL).

[000260] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is 600 µM (100 IU/mL).

[000261] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is 1200 µM (200 IU/mL).

[000262] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is 1800 µM (300 IU/mL).

[000263] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is 2400 µM (400 IU/mL).

[000264] In one embodiment, it relates to a pharmaceutical formulation characterized in that the insulin concentration is 3000 µM (500 IU/mL).

[000265] The invention relates to the use of at least one substituted anionic compound, said compound consisting of a saccharide backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from the group consisting of hexoses, in cyclic form or in open reduced form, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable to prepare a pharmaceutical formulation of human insulin, in combination with a polyanionic compound, making it possible, after administration, to accelerate the passage of the insulin into the blood and to reduce glycemia more rapidly when compared with a formulation free of substituted anionic compound, and optionally of anionic compounds.

[000266] In one embodiment, the invention relates to the use of at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, to prepare a pharmaceutical formulation of human insulin, in combination with a polyanionic compound, making it possible, after administration, to accelerate the passage of the human insulin into the blood and to reduce glycemia more rapidly when compared with a formulation free of substituted anionic compound, and optionally of anionic compounds.

[000267] In one embodiment, the invention relates to the use of at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, to prepare an insulin analog formulation, in combination with a polyanionic

compound, making it possible, after administration, to accelerate the passage of the insulin analog into the blood and to reduce glycemia more rapidly when compared with a formulation free of substituted anionic compound, and optionally of anionic compounds.

[000268] In one embodiment, the insulin is human insulin.

[000269] The term "human insulin" means an insulin obtained by synthesis or recombination, whose peptide sequence is the sequence of human insulin, including the allelic variations and homologs.

[000270] In one embodiment, the insulin is a recombinant human insulin as described in the European Pharmacopea and the American Pharmacopea.

[000271] In one embodiment, the insulin is an insulin analog.

[000272] The term "insulin analog" means a recombinant insulin whose primary sequence contains at least one modification relative to the primary sequence of human insulin.

[000273] In one embodiment, the insulin analog is chosen from the group consisting of the insulin lispro (Humalog®), the insulin aspart (Novolog®, Novorapid®) and the insulin glulisine (Apidra®).

[000274] In one embodiment, the insulin analog is the insulin lispro (Humalog®).

[000275] In one embodiment, the insulin analog is the insulin aspart (Novolog®, Novorapid®).

[000276] In one embodiment, the insulin analog is the insulin glulisine (Apidra®).

[000277] In one embodiment, the use is characterized in that the substituted anionic compound is chosen from substituted anionic compounds, in isolated form or as a mixture, consisting of a saccharide backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from hexoses, in cyclic form or in open reduced form, characterized in that they are substituted with:

a) at least one substituent of general formula I:

$$-[R_1]_a-[AA]_m \qquad \text{Formula I}$$

- the substituents being identical or different when there are at least two substituents, in which:
- the radical -[AA] denotes an amino acid residue,

- the radical -R_1- being:

  – either a bond and then a = 0 and the amino acid residue -[AA]- is directly linked to the backbone via a function G,

  – or a C2 to C15 carbon-based chain, and then a = 1, optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function before the reaction with the amino acid, said chain forming with the amino acid residue -[AA]- an amide function, and is attached to the backbone by means of a function F resulting from a reaction between a hydroxyl function borne by the backbone and a function or substituent borne by the precursor of the radical -R_1-,

- F is a function chosen from ether, ester and carbamate functions,
- G is a carbamate function,
- m is equal to 1 or 2,
- the degree of substitution of the saccharide units, j, in $-[R_1]_a-[AA]_m$ being strictly greater than 0 and less than or equal to 6, $0 < j \leq 6$

b) and, optionally, one or more substituents $-R'_1$,

- the substituent -R'_1 being a C2 to C15 carbon-based chain, which is optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function in the form of an alkali metal cation salt, said chain being linked to the backbone via a function F' resulting from a reaction between a hydroxyl function borne by the backbone and a function or substituent borne by the precursor of the substituent -R'_1,

- F' is an ether, ester or carbamate function,

- the degree of substitution of the saccharide units, i, in -R'_1, being between 0 and 6-j, $0 \leq i \leq 6-j$, and

- F and F' are identical or different,
- F and G are identical or different,
- $i+j \leq 6$,

- -R'_1 is identical to or different from $-R_1-$,

- the free salifiable acid functions borne by the substituent -R'_1 are in the form of alkali metal cation salts,

- said glycoside bonds, which may be identical or different, being chosen from the group consisting of glycoside bonds of (1,1), (1,2), (1,3), (1,4) or (1,6) type, in an alpha or beta geometry.

[000278] In one embodiment, the use is characterized in that the substituted anionic compound, in isolated form or as a mixture, is chosen from substituted anionic compounds consisting of a saccharide backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from hexoses, in cyclic form or in open reduced form, characterized

a) in that they are randomly substituted with:

- at least one substituent of general formula I:

$$-[R_1]_a-[AA]_m \qquad \text{Formula I}$$

- the substituents being identical or different when there are at least two substituents, in which:
- the radical –[AA]– denotes an amino acid residue, said amino acid being chosen from the group consisting of phenylalanine, alpha-methylphenylalanine, 3,4-dihydroxyphenylalanine, tyrosine, alpha-methyltyrosine, O-methyltyrosine, alpha-phenylglycine, 4-hydroxyphenylglycine and 3,5-dihydroxyphenylglycine, and the alkali metal cation salts thereof, said derivatives being in L or D absolute configuration, –[AA]– is attached to the backbone of the molecule via a linker arm $-R_1-$ or directly attached to the backbone via a function G,
- $-R_1-$ being:
  - either a bond G, and then a = 0,
  - or a C2 to C15 carbon-based chain, and then a = 1, optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and bearing at least one acid function before the reaction with the amino acid, said chain forming with the amino acid residue -[AA]- an amide bond, and is attached to the saccharide backbone by means of a function F resulting from a reaction between a hydroxyl function borne by the backbone and a function borne by the precursor of R_1,
- F is an ether, ester or carbamate function,
- G is a carbamate function,
- m is equal to 1 or 2,

- the degree of substitution, j, in $-[R_1]_a-[AA]_m$ being strictly greater than 0 and less than or equal to 6, $0 < j \leq 6$,

and, optionally,

- one or more substituents $-R'_1$
- $-R'_1$ being a C2 to C15 carbon-based chain, which is optionally substituted and/or comprising at least one heteroatom (such as O, N and S) and bearing at least one acid function in the form of an alkali metal cation salt, said chain being attached to the saccharide backbone via a function F' resulting from a reaction between a hydroxyl function borne by the backbone and a function borne by the precursor of $-R'_1$,
- F' is an ether, ester or carbamate function,
- the degree of substitution, i, in $-R'_1$, being between 0 and 6-j, $0 \leq i \leq 6-j$, and
- $-R'_1-$ is identical to or different from $-R_1$,
- F and F' are identical or different,
- F' and G are identical or different,
- the free salifiable acid functions are in the form of alkali metal cation salts,

b) said glycoside bonds, which may be identical or different, being chosen from the group consisting of glycoside bonds of (1,1), (1,2), (1,3), (1,4) or (1,6) type, in an alpha or beta geometry,

c) $i + j \leq 6$.

[000279] In one embodiment, m is equal to 1.

[000280] In one embodiment, -R1 and -R'1, which may be identical or different, are a C1 to C8 carbon-based chain.

[000281] In one embodiment, -R1 and -R'1, which may be identical or different, are a C1 to C4 carbon-based chain.

[000282] In one embodiment, -R1 and -R'1, which may be identical or different, are a C1 to C2 carbon-based chain.

[000283] It is known to those skilled in the art that the delay of action of insulins is dependent on the insulin concentration. Only the delay of action values for formulations at 100 IU/mL are documented.

[000284] "Regular" human insulin formulations on the market at a concentration of 600 µM (100 IU/mL) have a delay of action of between 50 and 90 minutes and an end of action of about 360 to 420 minutes in man. The time to achieve the maximum insulin concentration in the blood is between 90 and 180 minutes in man.

[000285] Rapid insulin analog formulations on the market at a concentration of 600 μM (100 IU/mL) have a delay of action of between 30 and 60 minutes and an end of action of about 240-300 minutes in man. The time to achieve the maximum insulin concentration in the blood is between 50 and 90 minutes in man.

[000286] The invention also relates to a method for preparing a human insulin formulation having an insulin concentration of between 240 and 3000 μM (40 and 500 IU/mL), whose delay of action in man is less than that of the reference formulation at the same insulin concentration in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000287] In one embodiment, the insulin is in hexameric form.

[000288] The invention also relates to a method for preparing a human insulin formulation having an insulin concentration of between 600 and 1200 μM (100 and 200 IU/mL), whose delay of action in man is less than that of the reference formulation at the same insulin concentration in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000289] In one embodiment, the insulin is in hexameric form.

[000290] The invention also relates to a method for preparing a human insulin formulation having an insulin concentration of 600 μM (100 IU/mL), whose delay of action in man is less than 60 minutes, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000291] In one embodiment, the insulin is in hexameric form.

[000292] The invention also relates to a method for preparing a human insulin formulation having an insulin concentration of 1200 μM (200 IU/mL), whose delay of

action in man is at least 10% less than that of the human insulin formulation at the same concentration (200 IU/mL) and in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000293] In one embodiment, the insulin is in hexameric form.

[000294] The invention also relates to a method for preparing a human insulin formulation having an insulin concentration of 1800 μM (300 IU/mL), whose delay of action in man is at least 10% less than that of the human insulin formulation at the same concentration (300 IU/mL) and in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000295] In one embodiment, the insulin is in hexameric form.

[000296] The invention also relates to a method for preparing a human insulin formulation having an insulin concentration of 2400 μM (400 IU/mL), whose delay of action in man is at least 10% less than that of the human insulin formulation at the same concentration (400 IU/mL) and in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000297] In one embodiment, the insulin is in hexameric form.

[000298] The invention also relates to a method for preparing a human insulin formulation having an insulin concentration of 3000 μM (500 IU/mL), whose delay of action in man is at least 10% less than that of the human insulin formulation at the same concentration (500 IU/mL) and in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the

unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000299] In one embodiment, the insulin is in hexameric form.

[000300] The invention consists in preparing a rapid human insulin formulation, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000301] In one embodiment, the insulin is in hexameric form.

[000302] The invention also relates to a method for preparing a human insulin formulation at a concentration of 600 µM (100 IU/mL), whose delay of action in man is less than 60 minutes, preferably less than 45 minutes and more preferably less than 30 minutes, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000303] In one embodiment, the insulin is in hexameric form.

[000304] The invention also relates to a method for preparing an insulin analog formulation having an insulin concentration of between 240 and 3000 µM (40 and 500 IU/mL), whose delay of action in man is less than that of the reference formulation at the same insulin concentration in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000305] In one embodiment, the insulin is in hexameric form.

[000306] The invention also relates to a method for preparing an insulin analog formulation having an insulin concentration of between 600 and 1200 µM (100 and 200 IU/mL), whose delay of action in man is less than that of the reference

formulation at the same insulin analog concentration in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000307] In one embodiment, the insulin is in hexameric form.

[000308] The invention also relates to a method for preparing an insulin analog formulation having an insulin concentration of 600 µmol/L (100 IU/mL), whose delay of action in man is less than 30 minutes, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000309] In one embodiment, the insulin is in hexameric form.

[000310] The invention also relates to a method for preparing an insulin analog formulation having an insulin concentration of 1200 µM (200 IU/mL), whose delay of action in man is at least 10% less than that of the insulin analog formulation in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000311] In one embodiment, the insulin is in hexameric form.

[000312] The invention also relates to a method for preparing an insulin analog formulation having an insulin concentration of 1800 µM (300 IU/mL), whose delay of action in man is at least 10% less than that of the insulin analog formulation in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being

salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000313] In one embodiment, the insulin is in hexameric form.

[000314] The invention also relates to a method for preparing an insulin analog formulation having an insulin concentration of 2400 µM (400 IU/mL), whose delay of action in man is at least 10% less than that of the insulin analog formulation in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000315] In one embodiment, the insulin is in hexameric form.

[000316] The invention also relates to a method for preparing an insulin analog formulation having an insulin concentration of 3000 µM (500 IU/mL), whose delay of action in man is at least 10% less than that of the insulin analog formulation in the absence of a substituted anionic compound and of a polyanionic compound, characterized in that it comprises (1) a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, and (2) a step of adding to said formulation at least one polyanionic compound.

[000317] In one embodiment, the insulin is in hexameric form.

[000318] The invention consists in preparing a very rapid insulin analog formulation, characterized in that it comprises a step of adding to said formulation at least one substituted anionic compound, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable.

[000319] In one embodiment, the preparation also comprises a step of adding to said formulation at least one polyanionic compound.

[000320] In one embodiment, the insulin is in hexameric form.

[000321] In one embodiment, the insulin analog is chosen from the group consisting of the insulin lispro (Humalog®), the insulin aspart (Novolog®, Novorapid®) and the insulin glulisine (Apidra®).

[000322] In one embodiment, the insulin analog is the insulin lispro (Humalog®).

[000323] In one embodiment, the insulin analog is the insulin aspart (Novolog®, Novorapid®).

[000324] In one embodiment, the insulin analog is the insulin glulisine (Apidra®).

[000325] In one embodiment, the insulin is a recombinant human insulin as described in the European Pharmacopea and the American Pharmacopea.

[000326] In one embodiment, the insulin is an insulin analog chosen from the group consisting of the insulin lispro (Humalog®), the insulin aspart (Novolog®, Novorapid®) and the insulin glulisine (Apidra®).

[000327] The composition may furthermore be prepared by simple mixing of an aqueous solution of human insulin or of insulin analog and an aqueous solution of substituted anionic compound as a mixture with a polyanionic compound.

[000328] In one embodiment, the composition may be prepared by simple mixing of an aqueous solution of human insulin or of insulin analog, an aqueous solution of substituted anionic compound and a polyanionic compound in solution or in lyophilizate form.

[000329] In one embodiment, the composition may be prepared by simple mixing of an aqueous solution of human insulin or of insulin analog, a substituted anionic compound in lyophilizate form and a polyanionic compound in solution or in lyophilizate form.

[000330] Preferably, this composition is in the form of an injectable solution.

[000331] In one embodiment, the concentration of human insulin or insulin analog is between 240 and 3000 μM (40 to 500 IU/mL).

[000332] In one embodiment, the concentration of human insulin or insulin analog is between 600 and 3000 μM (100 to 500 IU/mL).

[000333] In one embodiment, the concentration of human insulin or insulin analog is between 600 and 2400 μM (100 to 400 IU/mL).

[000334] In one embodiment, the concentration of human insulin or insulin analog is between 600 and 1800 μM (100 to 300 IU/mL).

[000335] In one embodiment, the concentration of human insulin or insulin analog is between 600 and 1200 μM (100 to 200 IU/mL).

[000336] In one embodiment, the concentration of human insulin or insulin analog is 600 μM (100 IU/mL).

[000337] In one embodiment, the concentration of human insulin or insulin analog is 1200 μM (200 IU/mL).

[000338] In one embodiment, the concentration of human insulin or insulin analog of 600 µM (100 IU/mL) may be reduced by simple dilution, in particular for pediatric applications.

[000339] In one embodiment, the concentration of human insulin or insulin analog is 1800 µM (300 IU/mL).

[000340] In one embodiment, the concentration of human insulin or insulin analog is 2400 µM (400 IU/mL).

[000341] In one embodiment, the concentration of human insulin or insulin analog is 3000 µM (500 IU/mL).

[000342] The invention also relates to a pharmaceutical formulation according to the invention, characterized in that it is obtained by drying and/or lyophilization.

[000343] In one embodiment, the compositions according to the invention also comprise the addition of zinc salts to a concentration of between 0 and 500 µM.

[000344] In one embodiment, the compositions according to the invention also comprise the addition of zinc salts to a concentration of between 0 and 300 µM.

[000345] In one embodiment, the compositions according to the invention also comprise the addition of zinc salts to a concentration of between 0 and 200 µM.

[000346] In one embodiment, the compositions according to the invention comprise buffers at concentrations of between 0 and 100 mM, preferably between 0 and 50 mM or between 15 and 50 mM.

[000347] In one embodiment, the buffer is Tris.

[000348] In one embodiment, the compositions according to the invention also comprise preservatives.

[000349] In one embodiment, the preservatives are chosen from the group consisting of *m*-cresol and phenol, alone or as a mixture.

[000350] In one embodiment, the concentration of preservatives is between 10 and 50 mM.

[000351] In one embodiment, the concentration of preservatives is between 10 and 40 mM.

[000352] The compositions according to the invention may also comprise additives such as tonicity agents, for instance glycerol, sodium chloride (NaCl), mannitol and glycine.

[000353] The compositions according to the invention may also comprise additives in accordance with the pharmacopeas, for instance surfactants, for example polysorbate.

[000354] The compositions according to the invention may also comprise any excipient in accordance with the pharmacopeas which are compatible with the insulins used at the working concentrations.

[000355] In the case of local and systemic release, the envisaged modes of administration are intravenous, subcutaneous, intradermal or intramuscular.

[000356] Transdermal, oral, nasal, vaginal, ocular, oral and pulmonary administration routes are also envisaged.

[000357] The invention also relates to the use of a composition according to the invention for the formulation of a solution of human insulin or insulin analog in a concentration of 100 IU/mL intended for implantable or transportable insulin pumps.

[000358] The invention also relates to the use of a composition according to the invention for the formulation of a solution of human insulin or insulin analog in a concentration of 200 IU/mL intended for implantable or transportable insulin pumps.

[000359] The invention also relates to substituted anionic compound, in isolated form or as a mixture, chosen from substituted anionic compounds consisting of a saccharide backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from hexoses, in cyclic form or in open reduced form, characterized in that they are substituted with:

a) at least one substituent of general formula I:

$$-[R_1]_a-[AA]_m \qquad \text{Formula I}$$

- the substituents being identical or different when there are at least two substituents, in which:
- the radical -[AA] denotes an amino acid residue,
- the radical -R_1- being:
  - either a bond and then a = 0 and the amino acid residue -[AA]- is directly linked to the backbone via a function G,
  - or a C2 to C15 carbon-based chain, and then a = 1, optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function before the reaction with the amino acid, said chain forming with the amino acid residue -[AA]- an amide function, and is attached to the backbone by means of a function F resulting from a reaction between a hydroxyl function borne by the backbone and a function or substituent borne by the precursor of the radical -R_1-,
- F is a function chosen from ether, ester and carbamate functions,
- G is a carbamate function,

- m is equal to 1 or 2,
- the degree of substitution of the saccharide units, j, in $-[R_1]_a-[AA]_m$ being strictly greater than 0 and less than or equal to 6, $0 < j \leq 6$

b) and, optionally, one or more substituents $-R'_1$,

- the substituent $-R'_1$ being a C2 to C15 carbon-based chain, which is optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function in the form of an alkali metal cation salt, said chain being linked to the backbone via a function F' resulting from a reaction between a hydroxyl function borne by the backbone and a function or substituent borne by the precursor of the substituent $-R'_1$,
- F' is an ether, ester or carbamate function,
- the degree of substitution of the saccharide units, i, in $-R'_1$, being between 0 and 6-j, $0 \leq i \leq 6-j$, and
- F and F' are identical or different,
- F and G are identical or different,
- $i+j \leq 6$,
- $-R'_1$ is identical to or different from $-R_1-$,
- the free salifiable acid functions borne by the substituent $-R'_1$ are in the form of alkali metal cation salts,
- said glycoside bonds, which may be identical or different, being chosen from the group consisting of glycoside bonds of (1,1), (1,2), (1,3), (1,4) or (1,6) type, in an alpha or beta geometry.

[000360] In the above formula, the different variables have the values mentioned above.

[000361] The substituted anionic compounds according to the invention may be obtained by random grafting of substituents onto the saccharide backbone.

[000362] In one embodiment, the substituted anionic compounds chosen from anionic compounds substituted with substituents of formula I or II are characterized in that they may be obtained by grafting substituents in precise positions onto the saccharide units via a process involving steps of protection/deprotection of the alcohol or carboxylic acid groups naturally borne by the backbone. This strategy leads to selective grafting, especially regioselective grafting, of the substituents onto the backbone. The protecting groups include, without limitation, those described in the

publication (Wuts, P.G.M. et al., Greene's Protective Groups in Organic Synthesis 2007).

[000363] The saccharide backbone may be obtained by degradation of a high molecular weight polysaccharide. The degradation routes include, without limitation, chemical degradation and/or enzymatic degradation.

[000364] The saccharide backbone may also be obtained by formation of glycoside bonds between monosaccharide or oligosaccharide molecules using a chemical or enzymatic coupling strategy. The coupling strategies include those described in the publication (Smooth, J.T. et al., Advances in Carbohydrate Chemistry and Biochemistry 2009, 62, 162-250) and in the publication (Lindhorst, T.K., Essentials of Carbohydrate Chemistry and Biochemistry 2007, 157-208). The coupling reactions may be performed in solution or on a solid support. The saccharide molecules before coupling may bear substituents of interest and/or may be functionalized once coupled together, randomly or regioselectively.

[000365] Thus, by way of example, the compounds according to the invention may be obtained according to one of the following processes:

- the random grafting of substituents onto a saccharide backbone
- one or more steps of glycosylation between monosaccharide or oligosaccharide molecules bearing substituents
- one or more steps of glycosylation between one or more monosaccharide or oligosaccharide molecules bearing substituents and one or more monosaccharide or oligosaccharide molecules
- one or more steps of introduction of protecting groups onto alcohols or acids naturally borne by the saccharide backbone, followed by one or more substituent grafting reactions and finally a step of removal of the protecting groups
- one or more steps of glycosylation between one or more monosaccharide or oligosaccharide molecules bearing protecting groups on alcohols or acids naturally borne by the saccharide backbone, one or more steps of grafting substituents onto the backbone obtained, and then a step of removal of the protecting groups
- one or more steps of glycosylation between one or more monosaccharide or oligosaccharide molecules bearing protecting groups on alcohols or acids naturally borne by the saccharide backbone, and one or more monosaccharide or oligosaccharide molecules, one or more substituent grafting steps and then a step of removal of the protecting groups.

[000366] The compounds according to the invention, isolated or as a mixture, may be separated and/or purified in various ways, especially after having been obtained via the processes described above.

[000367] Mention may be made in particular of chromatographic methods, especially "preparative" methods such as:

- flash chromatography, especially on silica, and
- chromatography such as HPLC (high-performance liquid chromatography), in particular RP-HPLC (reverse-phase HPLC).

[000368] Selective precipitation methods may also be used.

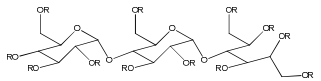
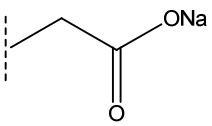
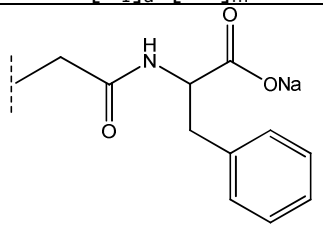
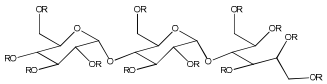
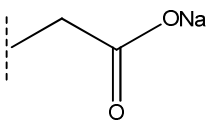
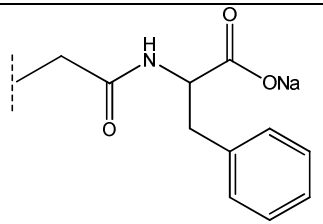
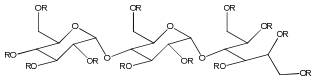
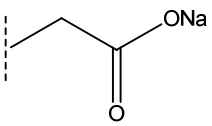
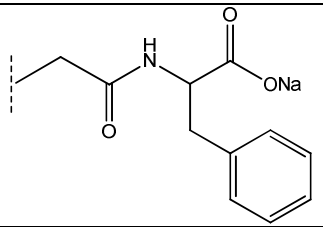
[000369] The invention is illustrated by the examples that follow.

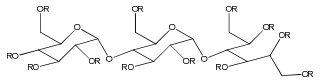
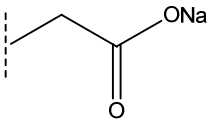
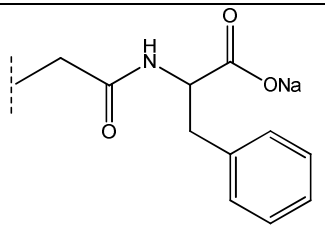
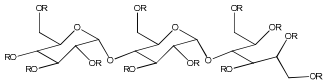
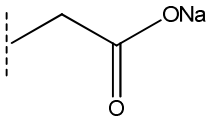
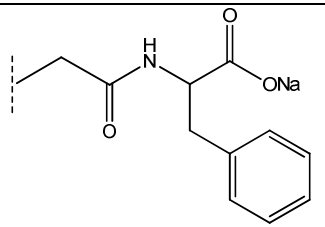
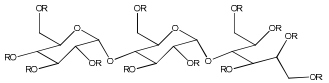
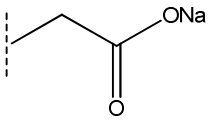
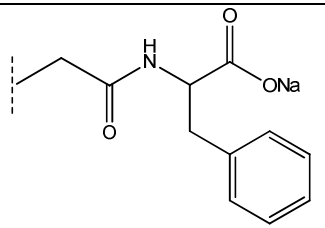
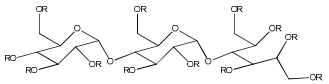
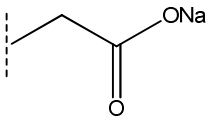
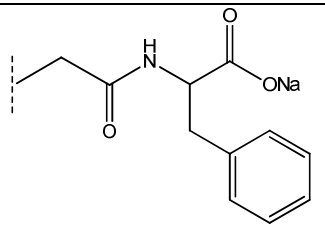
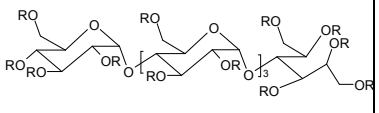
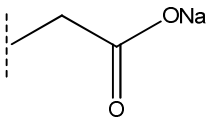
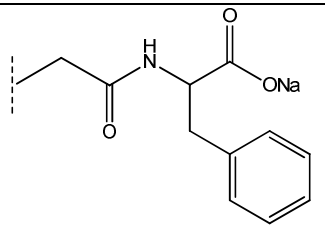
Examples

[000370] The structures of the substituted anionic compounds according to the invention are presented in Table 1. The structures of the polysaccharide counterexamples are presented in Table 2.

AA Substituted anionic compounds

R = H, R'_1, $-[R_1]_a-[AA]_m$

Compound	i	j	Saccharide chain	Substituent $-R'_1$	Substituent $-[R_1]_a-[AA]_m$
1	0.65	1.0			
2	1.0	0.65			
3	0.46	1.2			

4	0.35	0.65			
5	1.25	0.4			
6	0.8	0.65			
7	2.65	0.65			
8	1.0	0.75			

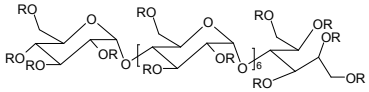
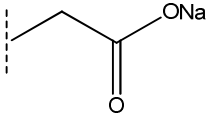
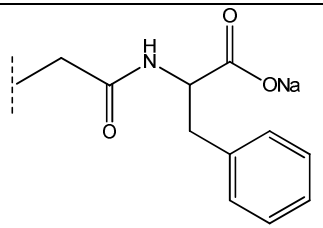
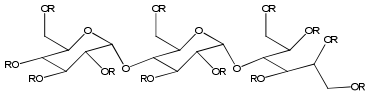
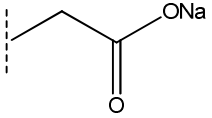
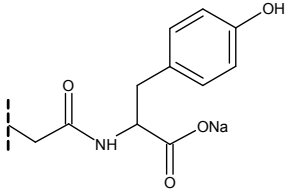
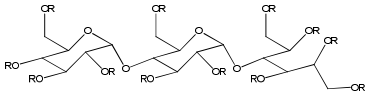
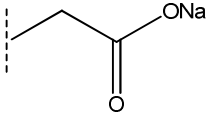
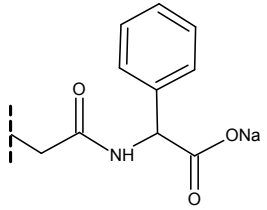
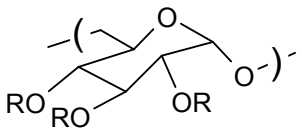
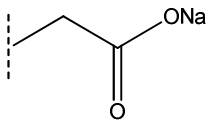
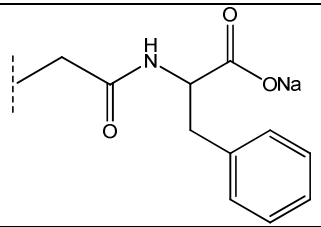
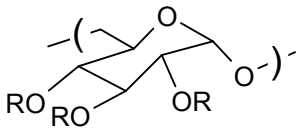
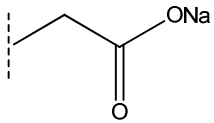
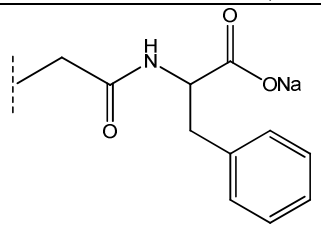
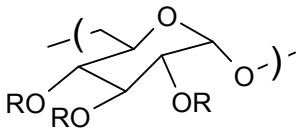
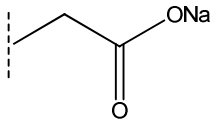
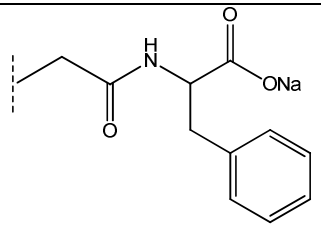
9	1.0	0.65			
10	0.83	0.81			
11	1.12	0.52			

Table 1

AB Polysaccharide counterexamples

Polysaccharide counterexamples	i	j	Saccharide chain	Weight-average molar mass (kg/mol)	Substituent – R'_1	Substituent - $[R_1]_a$-$[AA]_m$
Polysaccharide counterexamples AB1, AB2, AB3, AB4 and AB5: R = H, R'_1, -$[R_1]_a$-$[AA]_m$						
AB1	0.6	0.46		10		
AB2	1.01	0.64		5		
AB3	0.65	0.45		5		

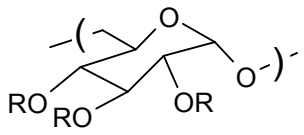
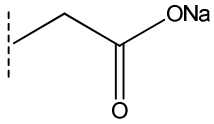
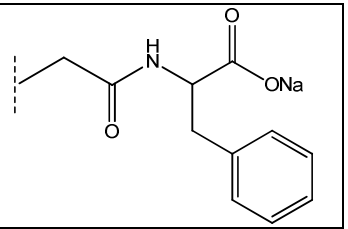
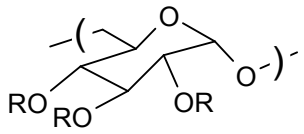
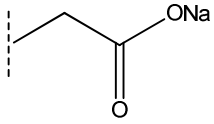
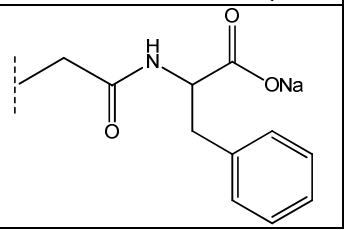
AB4	1.01	0.64		10		
AB5	0.45	0.65		5		

Table 2

AA1. Compound 1: Sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000371] To 8 g (143 mmol of hydroxyl functions) of maltotriose (CarboSynth) dissolved in water at 65°C is added 0.6 g (16 mmol) of sodium borohydride. After stirring for 30 minutes, 28 g (238 mmol) of sodium chloroacetate are added. To this solution are then added dropwise 24 mL of 10 N NaOH (24 mmol), and the mixture is then heated at 65°C for 90 minutes. 16.6 g (143 mmol) of sodium chloroacetate are then added to the reaction medium, along with dropwise addition of 14 mL of 10 N NaOH (14 mmol). After heating for 1 hour, the mixture is diluted with water, neutralized with acetic acid and then purified by ultrafiltration on a 1 kDa PES membrane against water. The molecule concentration of the final solution is determined on the dry extract, and an acid/base assay in a 50/50 (V/V) water/acetone mixture is then performed to determine the degree of substitution with methylcarboxylate.

[000372] According to the dry extract: [compound] = 32.9 mg/g

[000373] According to the acid/base assay, the degree of substitution with methylcarboxylate is 1.65 per saccharide unit.

[000374] The sodium maltotriosemethylcarboxylate solution is acidified on a Purolite resin (anionic) to obtain maltotriosemethylcarboxylic acid, which is then lyophilized for 18 hours.

[000375] 10 g of maltotriosemethylcarboxylic acid (63 mmol of methylcarboxylic acid functions) are dissolved in DMF and then cooled to 0°C. A mixture of ethyl phenylalaninate, hydrochloride salt (8.7 g, 38 mmol) in DMF is prepared. 3.8 g of triethylamine (38 mmol) are added to this mixture. A solution of NMM (6.3 g, 63 mmol) and of EtOCOCl (6.8 g, 63 mmol) is then added to the mixture at 0°C. The ethyl phenylalaninate solution is then added and the mixture is stirred at 10°C. An aqueous imidazole solution is added and the mixture is then heated to 30°C. The medium is diluted with water and the solution obtained is then purified by ultrafiltration on a 1 kDa PES membrane against 0.1 N NaOH, 0.9% NaCl and water. The molecule concentration of the final solution is determined on the dry extract. A sample of solution is lyophilized and analyzed by ^{1}H NMR in D_2O to determine the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate.

[000376] According to the dry extract: [compound 1] = 29.4 mg/g

[000377] According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 0.65 per saccharide unit.

[000378] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 1.0 per saccharide unit.

AA2. Compound 2: Sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000379] Via a process similar to that used for the preparation of compound 1, a sodium maltotriosecarboxylate functionalized with sodium L-phenylalaninate is obtained. According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 1.0 per saccharide unit.

[000380] According to the dry extract: [compound 2] = 20.2 mg/g

[000381] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.65 per saccharide unit.

AA3. Compound 3: Sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000382] Via a process similar to that used for the preparation of compound 1, a sodium maltotriosecarboxylate functionalized with sodium L-phenylalaninate is obtained. According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 0.46 per saccharide unit.

[000383] According to the dry extract: [compound 3] = 7.2 mg/g

[000384] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 1.2 per saccharide unit.

AA4. Compound 4: Sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000385] Via a process similar to that used for the preparation of compound 1, a sodium maltotriosecarboxylate functionalized with sodium L-phenylalaninate is obtained. According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 0.35 per saccharide unit.

[000386] According to the dry extract: [compound 4] = 3.1 mg/g

[000387] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.65 per saccharide unit.

AA5. Compound 5: Sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000388] Via a process similar to that used for the preparation of compound 1, a sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate is obtained.

[000389] According to the dry extract: [compound 5] = 10.9 mg/g

[000390] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.40 per saccharide unit.

[000391] The degree of substitution with sodium methylcarboxylates is 1.25 per saccharide unit.

AA6. Compound 6: Sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000392] To 8 g (143 mmol of hydroxyl functions) of maltotriose (CarboSynth) dissolved in water at 65°C is added 0.6 g (16 mmol) of sodium borohydride. After stirring for 30 minutes, 28 g (237 mmol) of sodium chloroacetate are added. To this solution are then added dropwise 24 mL of 10 N NaOH (240 mmol). After heating at 65°C for 90 minutes, the mixture is diluted with water, neutralized by adding acetic acid and then purified by ultrafiltration on a 1 kDa PES membrane against water. The compound concentration of the final solution is determined on the dry extract, and an acid/base assay in a 50/50 (V/V) water/acetone mixture is then performed to determine the degree of substitution with sodium methylcarboxylate.

[000393] According to the dry extract: [compound] = 14.5 mg/g

[000394] According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 1.45 per saccharide unit.

[000395] The sodium maltotriosemethylcarboxylate solution is acidified on a Purolite resin (anionic) to obtain maltotriosemethylcarboxylic acid, which is then lyophilized for 18 hours.

[000396] Via a process similar to that used for the preparation of compound 1, a sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate is obtained.

[000397] According to the dry extract: [compound 6] = 10.8 mg/g

[000398] According to the ^{1}H NMR, the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.65 per saccharide unit.

[000399] The degree of substitution with sodium methylcarboxylates is 0.8 per saccharide unit.

AA7. Compound 7: Sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000400] Via a process similar to that described in the preparation of compound 1, 8 g of sodium maltotriosemethylcarboxylate characterized by a degree of substitution with sodium methylcarboxylate of 1.76 are synthesized and lyophilized.

[000401] 8 g (58 mmol of hydroxyl functions) of the lyophilizate and 15 g (129 mmol) of sodium chloroacetate are dissolved in water at 65°C. To this solution are added dropwise 13 mL of 10 N NaOH (130 mmol) and the mixture is then heated at 65°C for 90 minutes. 9 g (78 mmol) of sodium chloroacetate are then added to the reaction medium,

along with dropwise addition of 8 mL of 10 N NaOH (80 mmol). After heating for 1 hour, the mixture is diluted with water, neutralized with acetic acid and then purified by ultrafiltration on a 1 kDa PES membrane against water. The compound concentration of the final solution is determined on the dry extract, and an acid/base assay in a 50/50 (V/V) water/acetone mixture is then performed to determine the degree of substitution with sodium methylcarboxylates.

[000402] According to the dry extract: [compound] = 11.7 mg/g

[000403] According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 3.30 per saccharide unit.

[000404] The sodium maltotriosemethylcarboxylate solution is acidified on a Purolite resin (anionic) to obtain maltotriosemethylcarboxylic acid, which is then lyophilized for 18 hours.

[000405] Via a process similar to that used for the preparation of compound 1, a sodium maltotriosemethylcarboxylate functionalized with sodium L-phenylalaninate is obtained.

[000406] According to the dry extract: [compound 7] = 14.9 mg/g

[000407] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.65 per saccharide unit.

[000408] The degree of substitution with sodium methylcarboxylates is 2.65 per saccharide unit.

AA8. Compound 8: Sodium maltopentaosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000409] Via a process similar to that described for the preparation of compound 1, but performed with maltopentaose (CarboSynth), 10 g of maltopentaosemethylcarboxylic acid with a degree of substitution with methylcarboxylic acid of 1.75 per saccharide unit are obtained and then lyophilized.

[000410] Via a process similar to that used for the preparation of compound 1, a sodium maltopentaosemethylcarboxylate functionalized with sodium L-phenylalaninate is obtained.

[000411] According to the dry extract: [compound 8] = 7.1 mg/g

[000412] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.75 per saccharide unit.

[000413] The degree of substitution with sodium methylcarboxylates is 1.0 per saccharide unit.

AA9. Compound 9: Sodium maltooctaosemethylcarboxylate functionalized with sodium L-phenylalaninate

[000414] Via a process similar to that described for the preparation of compound 1, but performed with maltooctaose (CarboSynth), 10 g of maltooctaosemethylcarboxylic acid with a degree of substitution with methylcarboxylic acid of 1.65 per saccharide unit are obtained and then lyophilized.

[000415] Via a process similar to that used for the preparation of compound 1, a sodium maltooctaosemethylcarboxylate functionalized with sodium L-phenylalaninate is obtained.

[000416] According to the dry extract: [compound 9] = 26.3 mg/g

[000417] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.65 per saccharide unit.

[000418] The degree of substitution with sodium methylcarboxylates is 1.0 per saccharide unit.

AA10. Compound 10: Sodium maltotriosemethylcarboxylate functionalized with sodium L-tyrosinate

[000419] Via a process similar to that described for the preparation of compound 1, but performed with methyl L-tyrosinate, hydrochloride salt (Bachem), a sodium maltotriosemethylcarboxylate, characterized by a degree of substitution with sodium methylcarboxylate per saccharide unit of 1.64, is functionalized with sodium L-tyrosinate.

[000420] According to the dry extract: [compound 10] = 9.1 mg/g

[000421] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-tyrosinate is 0.81 per saccharide unit.

The degree of substitution with sodium methylcarboxylates is 0.83 per saccharide unit.

AA11. Compound 11: Sodium maltotriosemethylcarboxylate functionalized with sodium alpha-phenylglycinate

[000422] Via a process similar to that described for the preparation of compound 1, 10 g of maltotriosemethylcarboxylic acid with a degree of substitution with methylcarboxylic acid of 1.64 per saccharide unit are obtained and then lyophilized.

[000423] 8 g of maltotriosemethylcarboxylic acid (50 mmol of methylcarboxylic acid functions) are dissolved in DMF and then cooled to 0°C. A mixture of sodium alpha-phenylglycinate (Bachem, 5 g; 33 mmol) and triethylamine (33 mmol) is prepared in water. A solution of NMM (4.9 g; 49 mmol) and of EtOCOCl (5.3 g, 49 mmol) is then added to the solution of maltotriosemethylcarboxylic acid at 0°C. The solution of sodium alpha-phenylglycinate and triethylamine is then added and the mixture is stirred at 30°C. An aqueous imidazole solution (340 g/L) is added after 90 minutes. The medium is

diluted with water and the solution obtained is then purified by ultrafiltration on a 1 kDa PES membrane against a 150 mM $NaHCO_3/Na_2CO_3$ pH 10.4 buffer, 0.9% NaCl and water. The compound concentration of the final solution is determined on the dry extract. A sample of solution is lyophilized and analyzed by ^1H NMR in D_2O to determine the degree of substitution with methylcarboxylates functionalized with sodium alpha-phenylglycinate.

[000424] According to the dry extract: [compound 11] = 9.1 mg/g

[000425] According to the ^1H NMR: the degree of substitution with methylcarboxylates functionalized with sodium alpha-phenylglycinate is 0.52 per saccharide unit.

[000426] The degree of substitution with sodium methylcarboxylates is 1.12 per saccharide unit.

AB Polysaccharide counterexamples

AB1. Polysaccharide 1: Sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate

[000427] Polysaccharide 1 is a sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate obtained from a dextran with a weight-average molar mass of 10 kg/mol (DP = 39, Pharmacosmos) according to the process described in patent application FR 07/02316 published under the number FR 2 914 305. According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 0.6 per saccharide unit.

[000428] According to the ^1H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.46 per saccharide unit.

[000429] This polysaccharide corresponds to polysaccharide 1 of patent application FR 09/01478.

AB2. Polysaccharide 2: Sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate

[000430] Polysaccharide 2 is a sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate obtained from a dextran with a weight-average molar mass of 5 kg/mol (DP = 19, Pharmacosmos) according to the process described in patent application FR 07/02316 published under the number FR 2 914 305. According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 1.01 per saccharide unit.

[000431] According to the ^1H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.64 per saccharide unit.

AB3. Polysaccharide 3: Sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate

[000432] Polysaccharide 3 is a sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate obtained from a dextran with a weight-average molar mass of 5 kg/mol (DP = 19, Pharmacosmos) according to the process described in patent application FR 07/02316 published under the number FR 2 914 305. According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 0.65 per saccharide unit.

[000433] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.45 per saccharide unit.

AB4. Polysaccharide 4: Sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate

[000434] Polysaccharide 4 is a sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate obtained from a dextran with a weight-average molar mass of 10 kg/mol (DP = 39, Pharmacosmos) according to the process described in patent application FR 07/02316 published under the number FR 2 914 305. According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 1.01 per saccharide unit.

[000435] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.64 per saccharide unit.

AB5. Polysaccharide 5: Sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate

[000436] Polysaccharide 5 is a sodium dextranmethylcarboxylate functionalized with sodium L-phenylalaninate obtained from a dextran with a weight-average molar mass of 5 kg/mol (DP = 19, Pharmacosmos) according to the process described in patent application FR 07/02316 published under the number FR 2 914 305. According to the acid/base assay, the degree of substitution with sodium methylcarboxylates is 0.45 per saccharide unit.

[000437] According to the ^{1}H NMR: the degree of substitution with methylcarboxylates functionalized with sodium L-phenylalaninate is 0.65 per saccharide unit.

AC Polyanionic compound

Polyanionic compound 1: Sodium maltotriosemethylcarboxylate

[000438] To 8 g (143 mmol of hydroxyl functions) of maltotriose (CarboSynth) dissolved in water at 65°C is added 0.6 g (16 mmol) of sodium borohydride. After stirring for 30 minutes, 28 g (238 mmol) of sodium chloroacetate are added. To this solution are then added dropwise 24 mL of 10 N NaOH (240 mmol), and the mixture is then heated at 65°C for 90 minutes. 16.6 g (143 mmol) of sodium chloroacetate are then added to the reaction medium, along with dropwise addition of 14 mL of 10 N NaOH (140 mmol). After heating for 1 hour, the mixture is diluted with water, neutralized with acetic acid and then purified by ultrafiltration on a 1 kDa PES membrane against water. The compound concentration of the final solution is determined on the dry extract, and an acid/base assay in a 50/50 (V/V) water/acetone mixture is then performed to determine the degree of substitution with sodium methylcarboxylate.

[000439] According to the dry extract: [polyanionic compound 1] = 32.9 mg/g

[000440] According to the acid/base assay: the degree of substitution with sodium methylcarboxylates is 1.65 per saccharide unit.

B Preparation of the solutions

B1. Solution of rapid insulin analog Novolog® at 100 IU/mL

[000441] This solution is a commercial solution of aspart insulin from Novo Nordisk sold under the name Novolog®. This product is an aspart rapid insulin analog.

B2. Solution of rapid insulin analog Humalog® at 100 IU/mL

[000442] This solution is a commercial solution of lispro insulin from Eli Lilly sold under the name Humalog®. This product is a rapid insulin analog.

B3. Solution of regular human insulin Actrapid® at 100 IU/mL

[000443] This solution is a commercial solution of human insulin from Novo Nordisk sold under the name Actrapid®. This product is a regular human insulin.

B4. Solution of regular human insulin Humulin® R at 100 IU/mL

[000444] This solution is a commercial solution of human insulin from Eli Lilly sold under the name Humulin® R. This product is a regular human insulin.

B5. Preparation of the excipient solutions

[000445] The non-polymeric polyanionic compounds are selected by measuring their dissociation constant with respect to calcium ions and with respect to their capacity for not destabilizing the hexameric form of insulin.

[000446] As regards the dissociation constant with respect to calcium ions, it is determined as follows.

[000447] Solutions containing 2.5 mM of $CaCl_2$, 150 mM of NaCl and increasing concentrations of polyanionic compound (between 0 and 20 mM) are prepared. The potential of all these formulations is measured and the concentrations of free calcium ions in the formulations are determined. After linearization by the Scatchard method, the dissociation constants are established. These data make it possible to compare the affinity of the carboxylates and phosphates of the various polyanionic compounds for Ca.

[000448] As regards their capacity for not destabilizing the hexameric form of insulin, this property is measured by circular dichroism in comparison with insulin alone (without anionic compound or polyanionic compound), see the experimental protocols in experimental section D.

Preparation of a sodium citrate solution at 1.188 M

[000449] A sodium citrate solution is obtained by dissolving 9.0811 g of sodium citrate (30.9 mmol) in 25 mL of water in a graduated flask. The pH is adjusted to exactly 7.4 by adding 1 mL of 1 M HCl. The solution is filtered through a 0.22 µm filter.

Preparation of a 130 mM *m*-cresol solution

[000450] An *m*-cresol solution is obtained by dissolving 14.114 g of *m*-cresol (130 mmol) in 986.4 mL of water in a 1 L graduated flask.

Preparation of a solution of *m*-cresol and glycerol (96.6 mM *m*-cresol and 566 mM glycerol)

[000451] 73.3 g of the 130 mM *m*-cresol solution are added to 5.26 g of glycerol and then diluted by addition of 22.25 g of water. The *m*-cresol and glycerol solution obtained is homogenized for 30 minutes and then filtered through a 0.22 µm membrane.

Preparation of a 32.7 mM Tween 20 solution

[000452] A Tween 20 solution is obtained by dissolving 2.0079 g of Tween 20 (1.636 mmol) in 50 mL of water in a graduated flask. The solution is filtered through a 0.22 µm membrane.

B6. Preparation of a 500 IU/mL human insulin solution

[000453] 15 g of water are added to 563.6 mg of human insulin and the pH is then lowered to acidic pH by adding 5.98 g of 0.1 N HCl. After total dissolution of the insulin at acidic pH, the solution is neutralized to pH 7.2 by adding 8.3 mL of 0.1 N NaOH. The concentration is then adjusted to 500 IU/mL by adding 0.76 g of water. The solution is finally filtered through a 0.22 µm membrane.

B7. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 1

[000454] For a final volume of 100 mL of formulation, with a [compound 1]/[lispro insulin] mass ratio of 2.0, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 1	730 mg
100 IU/mL Humalog® commercial solution	100 mL

[000455] The final pH is adjusted to 7.4 ± 0.4.

[000456] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B8. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 1 and citrate

[000457] For a final volume of 100 mL of formulation, with a [compound 1]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 1	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000458] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000459] The final pH is adjusted to 7.4 ± 0.4.

[000460] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B9. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 1 and the polyanionic compound 1

[000461] For a final volume of 100 mL of formulation, with a [compound 1]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2.0/2.0/1, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 1	730 mg
Lyophilized polyanionic compound 1	730 mg

100 IU/mL Humalog® commercial solution	100 mL

[000462] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000463] The final pH is adjusted to 7.4 ± 0.4.

[000464] The clear solution is filtered through a 0.22 μm membrane and stored at 4°C.

B10. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 1 and the polyanionic compound 1

[000465] For a final volume of 100 mL of formulation, with a [compound 1]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2.0/5.5/1, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 1	730 mg
Lyophilized polyanionic compound 1	2000 mg
100 IU/mL Humalog® commercial solution	100 mL

[000466] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000467] The final pH is adjusted to 7.4 ± 0.4.

[000468] The clear solution is filtered through a 0.22 μm membrane and stored at 4°C.

B11. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 2 and citrate

[000469] For a final volume of 100 mL of formulation, with a [compound 2]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 2	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 μL

[000470] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000471] The final pH is adjusted to 7.4 ± 0.4.

[000472] The clear solution is filtered through a 0.22 μm membrane and stored at 4°C.

B12. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 2 and the polyanionic compound 1

[000473] For a final volume of 100 mL of formulation, with a [compound 2]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2.0/2.0/1, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 2	730 mg
Lyophilized polyanionic compound 1	730 mg
100 IU/mL Humalog® commercial solution	100 mL

[000474] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000475] The final pH is adjusted to 7.4 ± 0.4.

[000476] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B13. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 2 and the polyanionic compound 1

[000477] For a final volume of 100 mL of formulation, with a [compound 2]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2.0/5.5/1, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 2	730 mg
Lyophilized polyanionic compound 1	2000 mg
100 IU/mL Humalog® commercial solution	100 mL

[000478] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000479] The final pH is adjusted to 7.4 ± 0.4.

[000480] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B14. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 1

[000481] For a final volume of 100 mL of formulation, with a [compound 1]/[lispro insulin] mass ratio of 4, the various reagents are added in the amounts specified below:

Compound 1 in lyophilized form	1460 mg
100 IU/mL Humalog® commercial solution	100 mL

[000482] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B15. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 2

[000483] For a final volume of 100 mL of formulation, with a [compound 2]/[lispro insulin] mass ratio of 4, the various reagents are added in the amounts specified below:

Compound 2 in lyophilized form	1460 mg
100 IU/mL Humalog® commercial solution	100 mL

[000484] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B16. Preparation of a 100 IU/mL lispro insulin analog solution in the presence of compound 1 and sodium tartrate

[000485] For a final volume of 100 mL of formulation, with a [compound 1]/[lispro insulin] mass ratio of 2.0 and a sodium tartrate concentration of 80 mM, the various reagents are added in the amounts specified below:

Compound 1 in lyophilized form	730 mg
100 IU/mL Humalog® commercial solution	100 mL
Sodium tartrate	1.552 g

[000486] For the tartrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000487] The final pH is adjusted to 7.4 ± 0.4.

[000488] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B17. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 1 and the polyanionic compound 1

[000489] For a final volume of 100 mL of formulation, with a [compound 1]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2/4/1, the various reagents are added in the amounts specified below:

Compound 1 in lyophilized form	730 mg
Polyanionic compound 1 in lyophilized form	1460 mg
100 IU/mL Humalog® commercial solution	100 mL

[000490] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000491] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B18. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 1 and sodium triphosphate

[000492] For a final volume of 100 mL of formulation, the various reagents are added in the amounts specified below:

Compound 1 in lyophilized form	730 mg
Sodium triphosphate	184 mg
100 IU/mL Humalog® commercial solution	100 mL

[000493] For the triphosphate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000494] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B19. Preparation of a 100 IU/mL lispro insulin analog solution in the presence of compound 2 and sodium tartrate

[000495] For a final volume of 100 mL of formulation, with a [compound 2]/[lispro insulin] mass ratio of 2.0 and a sodium tartrate concentration of 80 mM, the various reagents are added in the amounts specified below:

Compound 2 in lyophilized form	730 mg
100 IU/mL Humalog® commercial solution	100 mL
Sodium tartrate	1.552 g

[000496] For the tartrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000497] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B20. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 2 and the polyanionic compound 1

[000498] For a final volume of 100 mL of formulation, with a [compound 2]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2/4/1, the various reagents are added in the amounts specified below:

Compound 2 in lyophilized form	730 mg
Polyanionic compound 1 in lyophilized form	1460 mg
100 IU/mL Humalog® commercial solution	100 mL

[000499] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000500] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B21. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 2 and sodium triphosphate

[000501] For a final volume of 100 mL of formulation, the various reagents are added in the amounts specified below:

Compound 2 in lyophilized form	730 mg
Sodium triphosphate	184 mg
100 IU/mL Humalog® commercial solution	100 mL

[000502] For the triphosphate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000503] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B22. Preparation of a 200 IU/mL insulin analog (lispro insulin) solution

[000504] The commercial formulation of lispro insulin (Humalog®) was concentrated using Amicon Ultra-15 centrifugation tubes with a 3 kDa cut-off threshold. The Amicon tubes were first rinsed with 12 mL of deionized water. 12 mL of the commercial formulation were centrifuged for 35 minutes at 4000 g at 20°C. The volume of the retentate was measured and the concentration thus estimated. All the retentates were pooled and the overall concentration was estimated (> 200 IU/mL).

[000505] The concentration of this concentrated lispro insulin solution was adjusted to 200 IU/mL by adding the commercial lispro insulin formulation (Humalog®). The concentrated lispro insulin formulation has the same concentrations of excipients (*m*-cresol, glycerol, phosphate) as the commercial formulation at 100 IU/mL.

[000506] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B23. Preparation of a 200 IU/mL lispro insulin solution in the presence of compound 1 and citrate

[000507] For a final volume of 100 mL of formulation, with a [compound 1]/[lispro insulin] mass ratio of 2, the various reagents are mixed in the amounts specified below:

200 IU/mL lispro insulin	100 mL
Lyophilizate of compound 1	1460 mg
1.188 M sodium citrate solution	1566 µL

[000508] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B24. Preparation of a 200 IU/mL lispro insulin solution in the presence of compound 1 and the polyanionic compound 1

[000509] For a final volume of 100 mL of formulation, with a [compound 1]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2/2/1, the various reagents are mixed in the amounts specified below:

200 IU/mL lispro insulin	100 mL
Lyophilizate of compound 1	1460 mg
Lyophilizate of polyanionic compound 1	1460 mg

[000510] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000511] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B25. Preparation of a 200 IU/mL lispro insulin solution in the presence of compound 1 and the polyanionic compound 1

[000512] For a final volume of 100 mL of formulation, with a [compound 1]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2/4/1, the various reagents are mixed in the amounts specified below:

200 IU/mL lispro insulin	100 mL
Lyophilizate of compound 1	1460 mg
Lyophilizate of polyanionic compound 1	2920 mg

[000513] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000514] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B26. Preparation of a 200 IU/mL lispro insulin solution in the presence of compound 2 and the polyanionic compound 1

[000515] For a final volume of 100 mL of formulation, with a [compound 2]/[polyanionic compound 1]/[lispro insulin] mass ratio of 2/4/1, the various reagents are mixed in the amounts specified below:

200 IU/mL lispro insulin	100 mL
Lyophilizate of compound 2	1460 mg
Lyophilizate of polyanionic compound 1	2920 mg

[000516] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000517] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B27. Preparation of a 100 IU/mL human insulin solution in the presence of compound 1 and tartrate

[000518] For a final volume of 100 mL of formulation, with a [compound 1]/[human insulin] mass ratio of 2 and 80 mM of tartrate, the various reagents are mixed in the amounts specified below:

500 IU/mL human insulin	20 mL
36.01 mg/mL solution of compound 1	20.27 mL
96.6 mM *m*-cresol/566 mM glycerol solution	30 mL
Water	28.95 mL
Sodium tartrate	1.552 g

[000519] For the tartrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000520] The final pH is 7.4 ± 0.4. This clear solution is filtered through a 0.22 µm membrane and then placed at +4°C.

B28. Preparation of a 100 IU/mL human insulin solution in the presence of compound 1 and triphosphate

[000521] For a final volume of 100 mL of formulation, the various reagents are mixed in the amounts specified below:

500 IU/mL human insulin	20 mL
36.01 mg/mL solution of compound 1	20.27 mL
96.6 mM *m*-cresol/566 mM glycerol solution	30 mL
Water	28.95 mL
Sodium triphosphate	184 mg

[000522] For the triphosphate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000523] The final pH is 7.4 ± 0.4. This clear solution is filtered through a 0.22 µm membrane and then placed at +4°C.

B29. Preparation of a 100 IU/mL human insulin solution in the presence of compound 2 and tartrate

[000524] For a final volume of 100 mL of formulation, with a [compound 2]/[human insulin] mass ratio of 2 and 80 mM of tartrate, the various reagents are mixed in the amounts specified below:

500 IU/mL human insulin	20 mL
36.01 mg/mL solution of compound 2	20.27 mL
96.6 mM *m*-cresol/566 mM glycerol solution	30 mL
Water	28.95 mL
Sodium tartrate	1.552 g

[000525] For the tartrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000526] The final pH is 7.4 ± 0.4.

[000527] This clear solution is filtered through a 0.22 µm membrane and then placed at +4°C.

B30. Preparation of a 100 IU/mL human insulin solution in the presence of compound 2 and triphosphate

[000528] For a final volume of 100 mL of formulation, the various reagents are mixed in the amounts specified below:

500 IU/mL human insulin	20 mL
36.01 mg/mL solution of compound 2	20.27 mL
96.6 mM *m*-cresol/566 mM glycerol solution	30 mL
Water	28.95 mL
Sodium triphosphate	184 mg

[000529] For the triphosphate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000530] The final pH is 7.4 ± 0.4. This clear solution is filtered through a 0.22 µm membrane and then placed at +4°C.

B31. Preparation of a 200 IU/mL human insulin solution

[000531] The commercial formulation of human insulin (Humulin® R) was concentrated using Amicon Ultra-15 centrifugation tubes with a 3 kDa cut-off threshold. The Amicon tubes were first rinsed with 12 mL of deionized water. 12 mL of the commercial formulation were centrifuged for 35 minutes at 4000 g at 20°C. The volume of the retentate was measured and the concentration thus estimated. All the retentates were pooled and the overall concentration was estimated (> 200 IU/mL).

[000532] The concentration of this concentrated human insulin solution was adjusted to 200 IU/mL by adding the commercial human insulin formulation (Humulin® R). The

concentrated human insulin formulation has the same concentrations of excipients (*m*-cresol, glycerol) as the commercial formulation at 100 IU/mL.

[000533] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B32. Preparation of a 200 IU/mL human insulin solution in the presence of compound 1 and citrate

[000534] For a final volume of 100 mL of formulation, with a [compound 1]/[human insulin] mass ratio of 2, the various reagents are mixed in the amounts specified below:

200 IU/mL human insulin	100 mL
Lyophilizate of compound 1	1460 mg
1.188 M sodium citrate solution	1566 µL

[000535] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B33. Preparation of a 200 IU/mL human insulin solution in the presence of compound 1 and the polyanionic compound 1

[000536] For a final volume of 100 mL of formulation, with a [compound 1]/[polyanionic compound 1]/[human insulin] mass ratio of 2/2/1, the various reagents are mixed in the amounts specified below:

200 IU/mL human insulin	100 mL
Lyophilizate of compound 1	1460 mg
Lyophilizate of polyanionic compound 1	1460 mg

[000537] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B34. Preparation of a 200 IU/mL human insulin solution in the presence of compound 1 and the polyanionic compound 1

[000538] For a final volume of 100 mL of formulation, with a [compound 1]/[polyanionic compound 1]/[human insulin] mass ratio of 2/4/1, the various reagents are mixed in the amounts specified below:

200 IU/mL human insulin	100 mL
Lyophilizate of compound 1	1460 mg
Lyophilizate of polyanionic compound 1	2920 mg

[000539] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000540] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B35. Preparation of a 200 IU/mL human insulin solution in the presence of compound 2 and citrate

[000541] For a final volume of 100 mL of formulation, with a [compound 2]/[human insulin] mass ratio of 2, the various reagents are mixed in the amounts specified below:

200 IU/mL human insulin	100 mL
Lyophilizate of compound 2	1460 mg
1.188 M sodium citrate solution	1566 µL

[000542] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B36. Preparation of a 200 IU/mL human insulin solution in the presence of compound 2 and the polyanionic compound 1

[000543] For a final volume of 100 mL of formulation, with a [compound 2]/[polyanionic compound 1]/[human insulin] mass ratio of 2/2/1, the various reagents are mixed in the amounts specified below:

200 IU/mL human insulin	100 mL
Lyophilizate of compound 2	1460 mg
Lyophilizate of polyanionic compound 1	1460 mg

[000544] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000545] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B37. Preparation of a 200 IU/mL human insulin solution in the presence of compound 2 and the polyanionic compound 1

[000546] For a final volume of 100 mL of formulation, with a [compound 2]/[polyanionic compound 1]/[human insulin] mass ratio of 2/4/1, the various reagents are mixed in the amounts specified below:

200 IU/mL human insulin	100 mL
Lyophilizate of compound 2	1460 mg
Lyophilizate of polyanionic compound 1	2920 mg

[000547] The polyanionic compound 1 may be used in the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000548] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B38. Preparation of a 100 IU/mL human insulin solution in the presence of compound 2 and citrate

[000549] For a final volume of 100 mL of formulation, with a [compound 2]/[human insulin] mass ratio of 2 and 9.3 mM of citrate, the various reagents are mixed in the amounts specified below:

500 IU/mL human insulin	20 mL
36.01 mg/mL solution of compound 2	20.27 mL
96.6 mM *m*-cresol/566 mM glycerol solution	30 mL
Water	28.95 mL
1.188 M sodium citrate solution	783 µL

[000550] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000551] The final pH is 7.4 ± 0.4. This clear solution is filtered through a 0.22 µm membrane and then placed at +4°C.

B39. Preparation of a 100 IU/mL human insulin solution in the presence of compound 1 and citrate

[000552] For a final volume of 100 mL of formulation, with a [compound 1]/[human insulin] mass ratio of 2 and 9.3 mM of citrate, the various reagents are mixed in the amounts specified below:

500 IU/mL human insulin	20 mL
36.01 mg/mL solution of compound 1	27 mL
96.6 mM *m*-cresol/566 mM glycerol solution	30 mL
Water	28.95 mL
1.188 M sodium citrate solution	783 µL

[000553] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000554] The final pH is 7.4 ± 0.4. This clear solution is filtered through a 0.22 µm membrane and then placed at +4°C.

B40. Preparation of a 100 IU/mL aspart insulin solution in the presence of compound 1 and citrate

[000555] For a final volume of 100 mL of formulation, with a [compound 1]/[aspart insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 1	730 mg
100 IU/mL Novolog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000556] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000557] The final pH is adjusted to 7.4 ± 0.4.

[000558] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B41. 100 IU/mL solution of rapid insulin analog Apidra®

[000133] This solution is a commercial solution of glulisine insulin from Sanofi-Aventis sold under the name Apidra®. This product is a rapid insulin analog.

B42. Preparation of a 100 IU/mL glulisine insulin solution in the presence of compound 1 and citrate

[000559] For a final volume of 100 mL of formulation, with a [compound 1]/[glulisine insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 1	730 mg
100 IU/mL Apidra® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000560] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000561] The final pH is adjusted to 7.4 ± 0.4.

[000562] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B43. Preparation of a 100 IU/mL aspart insulin solution in the presence of compound 2 and citrate

[000563] For a final volume of 100 mL of formulation, with a [compound 2]/[aspart insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 2	730 mg
100 IU/mL Novolog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000564] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000565] The final pH is adjusted to 7.4 ± 0.4.

[000566] The clear solution is filtered through a 0.22 μm membrane and stored at 4°C.

B44. Preparation of a 100 IU/mL glulisine insulin solution in the presence of compound 2 and citrate

[000567] For a final volume of 100 mL of formulation, with a [compound 2]/[glulisine insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 2	730 mg
100 IU/mL Apidra® commercial solution	100 mL
1.188 M sodium citrate solution	783 μL

[000568] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000569] The final pH is adjusted to 7.4 ± 0.4.

[000570] The clear solution is filtered through a 0.22 μm membrane and stored at 4°C.

B45. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 5 and citrate

[000571] For a final volume of 100 mL of formulation, with a [compound 5]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 5	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 μL

[000572] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000573] The final pH is adjusted to 7.4 ± 0.4.

[000574] The clear solution is filtered through a 0.22 μm membrane and stored at 4°C.

B46. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 6 and citrate

[000575] For a final volume of 100 mL of formulation, with a [compound 6]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 6	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000576] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000577] The final pH is adjusted to 7.4 ± 0.4.

[000578] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B47. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 7 and citrate

[000579] For a final volume of 100 mL of formulation, with a [compound 7]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 7	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000580] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000581] The final pH is adjusted to 7.4 ± 0.4.

[000582] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B48. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 8 and citrate

[000583] For a final volume of 100 mL of formulation, with a [compound 8]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 8	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000584] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000585] The final pH is adjusted to 7.4 ± 0.4.

[000586] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B49. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 9 and citrate

[000587] For a final volume of 100 mL of formulation, with a [compound 9]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 9	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000588] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000589] The final pH is adjusted to 7.4 ± 0.4.

B50. Preparation of a 100 IU/mL human insulin solution in the presence of compound 5 and citrate

[000590] For a final volume of 100 mL of formulation, with a [compound 5]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 5	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000591] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000592] The final pH is adjusted to 7.4 ± 0.4.

[000593] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B51. Preparation of a 100 IU/mL human insulin solution in the presence of compound 6 and citrate

[000594] For a final volume of 100 mL of formulation, with a [compound 6]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 6	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000595] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000596] The final pH is adjusted to 7.4 ± 0.4.

[000597] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B52. Preparation of a 100 IU/mL human insulin solution in the presence of compound 7 and citrate

[000598] For a final volume of 100 mL of formulation, with a [compound 7]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 7	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000599] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000600] The final pH is adjusted to 7.4 ± 0.4.

[000601] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B53. Preparation of a 100 IU/mL human insulin solution in the presence of compound 8 and citrate

[000602] For a final volume of 100 mL of formulation, with a [compound 8]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 8	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000603] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000604] The final pH is adjusted to 7.4 ± 0.4.

[000605] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B54. Preparation of a 100 IU/mL human insulin solution in the presence of compound 9 and citrate

[000606] For a final volume of 100 mL of formulation, with a [compound 9]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 9	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000607] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000608] The final pH is adjusted to 7.4 ± 0.4.

[000609] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B55. Preparation of a 100 IU/mL human insulin solution in the presence of compound 2

[000610] For a final volume of 100 mL of formulation, with a [compound 2]/[human insulin] mass ratio of 2.0, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 2	730 mg
100 IU/mL Humulin® R commercial solution	100 mL

[000611] The final pH is adjusted to 7.4 ± 0.4.

[000612] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B56. Preparation of a 100 IU/mL human insulin solution in the presence of compound 7

[000613] For a final volume of 100 mL of formulation, with a [compound 7]/[human insulin] mass ratio of 2.0, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 7	730 mg
100 IU/mL Humulin® R commercial solution	100 mL

[000614] The final pH is adjusted to 7.4 ± 0.4.

[000615] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B57. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 10 and citrate

[000616] For a final volume of 100 mL of formulation, with a [compound 10]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 10	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000617] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000618] The final pH is adjusted to 7.4 ± 0.4.

[000619] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B58. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 11 and citrate

[000620] For a final volume of 100 mL of formulation, with a [compound 11]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 11	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000621] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000622] The final pH is adjusted to 7.4 ± 0.4.

B59. Preparation of a 100 IU/mL human insulin solution in the presence of compound 10 and citrate

[000623] For a final volume of 100 mL of formulation, with a [compound 10]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 10	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000624] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000625] The final pH is adjusted to 7.4 ± 0.4.

[000626] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B60. Preparation of a 100 IU/mL human insulin solution in the presence of compound 11 and citrate

[000627] For a final volume of 100 mL of formulation, with a [compound 11]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 11	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000628] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000629] The final pH is adjusted to 7.4 ± 0.4.

[000630] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B61. **Preparation of a 200 IU/mL aspart insulin solution**

[000631] The commercial formulation of aspart insulin (Novolog®) was concentrated using Amicon Ultra-15 centrifugation tubes with a 3 kDa cut-off threshold. The Amicon tubes were first rinsed with 12 mL of deionized water. 12 mL of the commercial formulation were centrifuged for 35 minutes at 4000 g at 20°C. The volume of the retentate was measured and the concentration thus estimated. All the retentates were pooled and the overall concentration was estimated (> 200 IU/mL).

[000632] The concentration of this concentrated aspart insulin solution was adjusted to 200 IU/mL by adding the commercial aspart insulin formulation (Novolog®). The concentrated aspart insulin formulation has the same concentrations of excipients (*m*-cresol, glycerol) as the commercial formulation at 100 IU/mL.

[000633] By modifying the centrifugation time and the final dilution with the commercial formulation, it is possible to prepare in the same manner aspart insulin formulations at 300, 400 or 500 IU/mL.

[000634] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B62. **Preparation of a 200 IU/mL glulisine insulin solution**

[000635] The commercial formulation of glulisine insulin (Apidra®) was concentrated using Amicon Ultra-15 centrifugation tubes with a 3 kDa cut-off threshold. The Amicon tubes were first rinsed with 12 mL of deionized water. 12 mL of the commercial formulation were centrifuged for 35 minutes at 4000 g at 20°C. The volume of the retentate was measured and the concentration thus estimated. All the retentates were pooled and the overall concentration was estimated (> 200 IU/mL).

[000636] The concentration of this concentrated glulisine insulin solution was adjusted to 200 IU/mL by adding the commercial glulisine insulin formulation (Apidra®). The concentrated glulisine insulin formulation has the same concentrations of excipients (*m*-cresol, NaCl, TRIS) as the commercial formulation at 100 IU/mL.

[000637] By modifying the centrifugation time and the final dilution with the commercial formulation, it is possible to prepare in the same manner glulisine insulin formulations at 300, 400 or 500 IU/mL.

[000638] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B63. **Preparation of a 200 IU/mL aspart insulin solution in the presence of compound 1 at 14.6 mg/mL and 18.6 mM citrate**

[000639] For a final volume of 100 mL of formulation, with a [compound 1]/[aspart insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below and in the following order:

Lyophilizate of compound 1	1460 mg
200 IU/mL aspart insulin	100 mL
1.188 M sodium citrate solution	1566 µL

[000640] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B64. Preparation of a human insulin, lispro insulin, aspart insulin or glulisine insulin solution at 300, 400 and 500 IU/mL

[000641] Concentrated formulations of human insulin, lispro insulin, aspart insulin or glulisine insulin at 300 IU/mL, 400 IU/mL or 500 IU/mL (and also at all intermediate concentrations) are prepared on the basis of the protocol of example B62 relating to the preparation of a 200 IU/mL glulisine insulin solution. The commercial insulin formulation is concentrated using Amicon Ultra-15 centrifugation tubes with a 3 kDa cut-off threshold. The Amicon tubes are first rinsed with 12 mL of deionized water. 12 mL of the commercial formulation are centrifuged at 4000 g at 20°C. By modifying the centrifugation time, it is possible to adjust the final concentration of insulin in the formulation. The volume of the retentate is measured and the concentration is thus estimated. All the retentates are pooled and the overall concentration is estimated (> 300, 400 or 500 IU/mL).

[000642] The concentration of this concentrated insulin solution is adjusted to the desired concentration (e.g. 300 IU/mL, 400 IU/mL or 500 IU/mL) by addition of the insulin formulation (Humulin® R, Novolog®, Humalog® or Apidra®). The concentrated insulin formulation has the same concentrations of excipients as the commercial formulation at 100 IU/mL.

[000643] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B65. Preparation of a 200 IU/mL glulisine insulin solution in the presence of compound 1 and citrate

[000644] For a final volume of 100 mL of formulation, with a [compound 1]/[glulisine insulin] mass ratio of 2, the various reagents are mixed in the amounts specified below and in the following order:

Lyophilizate of compound 1	1460 mg
200 IU/mL glulisine insulin	100 mL
1.188 M sodium citrate solution	1566 µL

[000645] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B66. **Preparation of a 300 IU/mL aspart insulin solution in the presence of compound 1 and citrate**

[000646] For a final volume of 100 mL of formulation, with a [compound 1]/[aspart insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

300 IU/mL aspart insulin	100 mL
Lyophilizate of compound 1	2190 mg
Sodium citrate	720 mg

[000647] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B67. Preparation of a 300 IU/mL glulisine insulin solution in the presence of compound 1 and citrate

[000648] For a final volume of 100 mL of formulation, with a [compound 1]/[glulisine insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

300 IU/mL glulisine insulin	100 mL
Lyophilizate of compound 1	2190 mg
Sodium citrate	720 mg

[000649] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B68. **Preparation of a 400 IU/mL aspart insulin solution in the presence of compound 1 and citrate**

[000650] For a final volume of 100 mL of formulation, with a [compound 1]/[aspart insulin] mass ratio of 2, the various reagents are mixed in the amounts specified below:

400 IU/mL aspart insulin	100 mL
Lyophilizate of compound 1	2920 mg
Sodium citrate	960 mg

[000651] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B69. **Preparation of a 400 IU/mL glulisine insulin solution in the presence of compound 1 and citrate**

[000652] For a final volume of 100 mL of formulation, with a [compound 1]/[glulisine insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

400 IU/mL glulisine insulin	100 mL
Lyophilizate of compound 1	2920 mg
Sodium citrate	960 mg

[000653] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B70. **Preparation of a 500 IU/mL aspart insulin solution in the presence of compound 1 and citrate**

[000654] For a final volume of 100 mL of formulation, with a [compound 1]/[aspart insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

500 IU/mL aspart insulin	100 mL
Lyophilizate of compound 1	3650 mg
Sodium citrate	1200 mg

[000655] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B71. **Preparation of a 500 IU/mL glulisine insulin solution in the presence of compound 1 and citrate**

[000656] For a final volume of 100 mL of formulation, with a [compound 1]/[glulisine insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

500 IU/mL glulisine insulin	100 mL
Lyophilizate of compound 1	3650 mg
Sodium citrate	1200 mg

[000657] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B72. **Preparation of a 300 IU/mL human insulin solution in the presence of compound 1 and citrate**

[000658] For a final volume of 100 mL of formulation, with a [compound 1]/[human insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

300 IU/mL human insulin	100 mL
Lyophilizate of compound 1	2190 mg

Sodium citrate	720 mg

[000659] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B73. **Preparation of a 300 IU/mL lispro insulin solution in the presence of compound 1 and citrate**

[000660] For a final volume of 100 mL of formulation, with a [compound 1]/[lispro insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

300 IU/mL lispro insulin	100 mL
Lyophilizate of compound 1	2190 mg
Sodium citrate	720 mg

[000661] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B74. **Preparation of a 400 IU/mL human insulin solution in the presence of compound 1 and citrate**

[000662] For a final volume of 100 mL of formulation, with a [compound 1]/[human insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

400 IU/mL human insulin	100 mL
Lyophilizate of compound 1	2920 mg
Sodium citrate	960 mg

[000663] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B75. **Preparation of a 400 IU/mL lispro insulin solution in the presence of compound 1 and citrate**

[000664] For a final volume of 100 mL of formulation, with a [compound 1]/[lispro insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

400 IU/mL lispro insulin	100 mL
Lyophilizate of compound 1	2920 mg
Sodium citrate	960 mg

[000665] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B76. **Preparation of a 500 IU/mL human insulin solution in the presence of compound 1 and citrate**

[000666] For a final volume of 100 mL of formulation, with a [compound 1]/[human insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

500 IU/mL human insulin	100 mL
Lyophilizate of compound 1	3650 mg
Sodium citrate	1200 mg

[000667] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B77. **Preparation of a 500 IU/mL lispro insulin solution in the presence of compound 1 and citrate**

[000668] For a final volume of 100 mL of formulation, with a [compound 1]/[lispro insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

500 IU/mL lispro insulin	100 mL
Lyophilizate of compound 1	3650 mg
Sodium citrate	1200 mg

[000669] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B78. **Preparation of a 200 IU/mL lispro insulin solution in the presence of compound 2 and citrate**

[000670] For a final volume of 100 mL of formulation, with a [compound 2]/[lispro insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

200 IU/mL lispro insulin	100 mL
Lyophilizate of compound 2	1460 mg
1.188 M sodium citrate solution	1566 µL

[000671] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B79. **Preparation of a 200 IU/mL aspart insulin solution in the presence of compound 2 and citrate**

[000672] For a final volume of 100 mL of formulation, with a [compound 2]/[aspart insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

200 IU/mL aspart insulin	100 mL
Lyophilizate of compound 2	1460 mg
1.188 M sodium citrate solution	1566 µL

[000673] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B80. **Preparation of a 200 IU/mL glulisine insulin solution in the presence of compound 2 and citrate**

[000674] For a final volume of 100 mL of formulation, with a [compound 2]/[glulisine insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

200 IU/mL glulisine insulin	100 mL
Lyophilizate of compound 2	1460 mg
1.188 M sodium citrate solution	1566 µL

[000675] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B81. **Preparation of a 300 IU/mL aspart insulin solution in the presence of compound 2 and citrate**

[000676] For a final volume of 100 mL of formulation, with a [compound 2]/[aspart insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

300 IU/mL aspart insulin	100 mL
Lyophilizate of compound 2	2190 mg
Sodium citrate	720 mg

[000677] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B82. **Preparation of a 300 IU/mL glulisine insulin solution in the presence of compound 2 and citrate**

[000678] For a final volume of 100 mL of formulation, with a [compound 2]/[glulisine insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

300 IU/mL glulisine insulin	100 mL
Lyophilizate of compound 2	2190 mg
Sodium citrate	720 mg

[000679] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B83. **Preparation of a 400 IU/mL aspart insulin solution in the presence of compound 2 and citrate**

[000680] For a final volume of 100 mL of formulation, with a [compound 2]/[aspart insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

400 IU/mL aspart insulin	100 mL
Lyophilizate of compound 2	2920 mg
Sodium citrate	960 mg

[000681] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B84. **Preparation of a 400 IU/mL glulisine insulin solution in the presence of compound 2 and citrate**

[000682] For a final volume of 100 mL of formulation, with a [compound 2]/[glulisine insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

400 IU/mL glulisine insulin	100 mL
Lyophilizate of compound 2	2920 mg
Sodium citrate	960 mg

[000683] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B85. **Preparation of a 500 IU/mL aspart insulin solution in the presence of compound 2 and citrate**

[000684] For a final volume of 100 mL of formulation, with a [compound 2]/[aspart insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

500 IU/mL aspart insulin	100 mL
Lyophilizate of compound 2	3650 mg
Sodium citrate	1200 mg

[000685] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B86. **Preparation of a 500 IU/mL glulisine insulin solution in the presence of compound 2 and citrate**

[000686] For a final volume of 100 mL of formulation, with a [compound 2]/[glulisine insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

500 IU/mL glulisine insulin	100 mL
Lyophilizate of compound 2	3650 mg
Sodium citrate	1200 mg

[000687] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B87. **Preparation of a 300 IU/mL human insulin solution in the presence of compound 2 and citrate**

[000688] For a final volume of 100 mL of formulation, with a [compound 2]/[human insulin] mass ratio of 2, the various reagents are mixed in the amounts specified below:

300 IU/mL human insulin	100 mL
Lyophilizate of compound 2	2190 mg
Sodium citrate	720 mg

[000689] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B88. **Preparation of a 300 IU/mL lispro insulin solution in the presence of compound 2 and citrate**

[000690] For a final volume of 100 mL of formulation, with a [compound 2]/[lispro insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

300 IU/mL lispro insulin	100 mL
Lyophilizate of compound 2	2190 mg
Sodium citrate	720 mg

[000691] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B89. **Preparation of a 400 IU/mL human insulin solution in the presence of compound 2 and citrate**

[000692] For a final volume of 100 mL of formulation, with a [compound 2]/[human insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

400 IU/mL human insulin	100 mL
Lyophilizate of compound 2	2920 mg
Sodium citrate	960 mg

[000693] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B90. **Preparation of a 400 IU/mL lispro insulin solution in the presence of compound 2 and citrate**

[000694] For a final volume of 100 mL of formulation, with a [compound 2]/[lispro insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

400 IU/mL lispro insulin	100 mL
Lyophilizate of compound 2	2920 mg
Sodium citrate	960 mg

[000695] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B91. **Preparation of a 500 IU/mL human insulin solution in the presence of compound 2 and citrate**

[000696] For a final volume of 100 mL of formulation, with a [compound 2]/[human insulin] mass ratio of 2.0, the various reagents are mixed in the amounts specified below:

500 IU/mL human insulin	100 mL
Lyophilizate of compound 2	3650 mg
Sodium citrate	1200 mg

[000697] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B92. **Preparation of a 500 IU/mL lispro insulin solution in the presence of compound 2 and citrate**

[000698] For a final volume of 100 mL of formulation, with a [compound 2]/[lispro insulin] mass ratio of 2.0, the various reagents are added in the amounts specified below:

500 IU/mL lispro insulin	100 mL
Lyophilizate of compound 2	3650 mg
Sodium citrate	1200 mg

[000699] The final pH is adjusted to 7.4 ± 0.4. The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B93. **Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 3 and citrate**

[000700] For a final volume of 100 mL of formulation, with a [compound 3]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 3	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000701] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000702] The final pH is adjusted to 7.4 ± 0.4.

[000703] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B94. Preparation of a 100 IU/mL lispro insulin solution in the presence of compound 4 and citrate

[000704] For a final volume of 100 mL of formulation, with a [compound 4]/[lispro insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 4	730 mg
100 IU/mL Humalog® commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000705] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000706] The final pH is adjusted to 7.4 ± 0.4.

[000707] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B95. Preparation of a 100 IU/mL human insulin solution in the presence of compound 3 and citrate

[000708] For a final volume of 100 mL of formulation, with a [compound 3]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 3	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000709] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000710] The final pH is adjusted to 7.4 ± 0.4.

[000711] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

B96. **Preparation of a 100 IU/mL human insulin solution in the presence of compound 4 and citrate**

[000712] For a final volume of 100 mL of formulation, with a [compound 4]/[human insulin] mass ratio of 2.0 and a citrate concentration of 9.3 mM, the various reagents are added in the amounts specified below and in the following order:

Lyophilized compound 4	730 mg
100 IU/mL Humulin® R commercial solution	100 mL
1.188 M sodium citrate solution	783 µL

[000713] For the citrate, use may be made of the acid form or the basic form in the form of the sodium salt, the potassium salt or another salt that is compatible with an injectable formulation.

[000714] The final pH is adjusted to 7.4 ± 0.4.

[000715] The clear solution is filtered through a 0.22 µm membrane and stored at 4°C.

C Pharmacodynamics and pharmacokinetics

C1: Protocol for measuring the pharmacodynamics of the insulin solutions

[000716] Twelve domestic pigs weighing about 50 kg, catheterized beforehand in the jugular vein, are fasted for 2.5 hours before the start of the experiment. In the hour preceding the injection of insulin, three blood samples are taken in order to determine the basal level of glucose and of insulin.

[000717] The injection of insulin at a dose of 0.09 IU/kg for lispro insulin and at a dose of 0.125 IU/kg for human insulin and aspart insulin is performed subcutaneously into the neck, under the animal's ear, using a Novopen insulin pen equipped with a 31 G needle.

[000718] Blood samples are then taken every 4 minutes for 20 minutes and then every 10 minutes up to 3 hours. After taking each sample, the catheter is rinsed with a dilute heparin solution.

[000719] A drop of blood is taken to determine the glycemia using a glucometer.

[000720] The glucose pharmacodynamic curves are then plotted and the time required to reach the minimum glucose level in the blood for each pig is determined and reported as the glucose Tmin. The mean of the glucose Tmin values is then calculated.

[000721] The remaining blood is collected in a dry tube and is centrifuged to isolate the serum. The insulin levels in the serum samples are measured via the sandwich ELISA immunoenzymatic method for each pig.

[000722] The pharmacokinetic curves are then plotted. The time required to reach the maximum insulin concentration in the serum for each pig is determined and reported as the insulin Tmax. The mean of the insulin Tmax values is then calculated.

C2: Pharmacodynamic and pharmacokinetic results for the insulin solutions of examples B2 and B8

Example	Insulin	Compound	Polyanionic compound	Number of pigs
B2	Lispro	-	-	11
B8	Lispro	1	Citrate 9.3 mM	10

[000723] The pharmacodynamic results obtained with the formulations described in examples B2 and B8 are presented in figure 1. According to the invention, the analysis of these curves shows that the formulation of example B8 comprising compound 1 and citrate at 9.3 mM as excipient (curve plotted with the squares corresponding to example B8, glucose Tmin = 30 ± 11 min) makes it possible to obtain more rapid action than that obtained with the Humalog® commercial formulation of example B2 (curve plotted with the triangles corresponding to example B2, glucose Tmin = 44 ± 14 min).

[000724] The pharmacokinetic results obtained with the formulations described in examples B2 and B8 are presented in figure 2. According to the invention, the analysis of these curves shows that the formulation of example B8 comprising compound 1 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B8, insulin Tmax = 11 ± 6 min) induces more rapid absorption of the lispro insulin than that of the Humalog® commercial formulation of example B2 (curve plotted with the triangles corresponding to example B2, insulin Tmax = 18 ± 8 min).

C3: Pharmacodynamic and pharmacokinetic results for the insulin solutions of examples B2 and B10

Example	Insulin	Compound	Polyanionic compound	Number of pigs
B2	Lispro	-	-	11
B10	Lispro	1	Polyanionic compound 1	11

[000725] The pharmacodynamic results obtained with the formulations described in examples B2 and B10 are presented in figure 3. According to the invention, the analysis of these curves shows that the formulation of example B10 comprising compound 1 and the polyanionic compound 1 as excipients at 20 mg/mL (curve plotted with the squares corresponding to example B10, glucose Tmin = 33 ± 13 min) makes it possible to obtain

more rapid action than that obtained with the Humalog® commercial formulation of example B2 (curve plotted with the triangles corresponding to example B2, glucose Tmin = 44 ± 14 min).

[000726] The pharmacokinetic results obtained with the formulations described in examples B2 and B10 are presented in figure 4. According to the invention, the analysis of these curves shows that the formulation of example B10 comprising compound 1 and the polyanionic compound 1 as excipients at 20 mg/mL (curve plotted with the squares corresponding to example B10, insulin Tmax = 15 ± 9 min) induces more rapid absorption of the lispro insulin than that of the Humalog® commercial formulation of example B2 (curve plotted with the triangles corresponding to example B2, insulin Tmax = 18 ± 8 min).

C4: Pharmacodynamic and pharmacokinetic results for the insulin solutions of examples B2 and B7

Example	Insulin	Compound	Polyanionic compound	Number of pigs
B2	Lispro	-	-	12
B7	Lispro	1	-	12

[000727] The pharmacodynamic results obtained with the formulations described in examples B2 and B7 are presented in figure 5. According to the invention, the analysis of these curves shows that the formulation of example B7 comprising compound 1 as excipient (curve plotted with the squares corresponding to example B7, glucose Tmin = 41 ± 16 min) includes more rapid onset of action than that obtained with the Humalog® commercial formulation of example B2 (curve plotted with the triangles corresponding to example B2, glucose Tmin = 50 ± 14 min).

[000728] The pharmacokinetic results obtained with the formulations described in examples B2 and B7 are presented in figure 6. The analysis of these curves shows that the formulation comprising compound 1 as excipient (curve plotted with the squares corresponding to example B2, insulin Tmax = 21 ± 10 min) does not induce more rapid absorption of the lispro insulin than that of the Humalog® commercial formulation of example B2 (curve plotted with the triangles corresponding to example B2 (insulin Tmax = 20 ± 9 min). Compound 1 alone is therefore insufficient to induce significant acceleration of the pharmacokinetics of lispro insulin.

C5: Pharmacodynamic and pharmacokinetic results for the insulin solutions of examples B1 and B3

Example	Insulin	Compound	Polyanionic compound	Number of pigs
B1	Aspart	-	-	11
B3	Human	-	-	11

[000729] The pharmacodynamic results obtained with the formulations described in examples B1 and B3 are presented in figure 7. The analysis of these curves shows that the human insulin formulation of example B3 (curve plotted with the squares corresponding to example B3, glucose Tmin = 61 ± 31 min) does indeed have slower action than that of the aspart insulin commercial formulation of example B1 (curve plotted with the triangles corresponding to example B1, glucose Tmin = 44 ± 13 min).

[000730] The pharmacokinetic results obtained with the formulations described in examples B1 and B3 are presented in figure 8. The analysis of these curves shows that the human insulin formulation alone of example B3 (curve plotted with the squares corresponding to example B3, insulin Tmax = 36 ± 33 min) does indeed induce slower absorption than that of the aspart insulin commercial formulation (Novolog®) of example B1 (curve plotted with the triangles corresponding to example B1, insulin Tmax = 28 ± 13 min).

[000731] These results are in accordance with the literature results, with acceleration of the lowering of glycemia and of the absorption of insulin for a rapid insulin analog relative to a human insulin.

C6: Pharmacodynamic and pharmacokinetic results for the insulin solutions of examples B1 and B39

Example	Insulin	Compound	Polyanionic compound	Number of pigs
B1	Aspart	-	-	14
B39	Human	1	Citrate 9.3 mM	5

[000732] The pharmacodynamic results obtained with the formulations described in examples B1 and B39 are presented in figure 9. The analysis of these curves shows that the formulation based on human insulin of example B39 comprising compound 1 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B39, glucose Tmin = 46 ± 9 min) makes it possible to obtain similar action to that obtained with the aspart insulin commercial formulation (Novolog®) of example B1 (curve plotted with the triangles corresponding to example B1, glucose Tmin = 53 ± 24 min).

[000733] The pharmacokinetic results obtained with the formulations described in examples B1 and B39 are presented in figure 10. The analysis of these curves shows that the formulation of example B39 comprising compound 1 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B39, insulin Tmax = 20 ± 7 min) induces insulin absorption similar to that obtained with the aspart insulin commercial formulation (Novolog®) of example B1 (curve plotted with the triangles corresponding to example B1, insulin Tmax = 22 ± 10 min).

[000734] Since the time parameters for the aspart insulin (Novolog®) between examples C5 and C6 are similar, it may be deduced by extrapolation that the formulation of example B39 induces acceleration of the lowering of glycemia and of the absorption of human insulin relative to the commercial formulation of human insulin (example B3).

C7: Pharmacodynamic and pharmacokinetic results for the insulin solutions of examples B2 and B11

Example	Insulin	Compound	Polyanionic compound	Number of pigs
B2	Lispro	-	-	26
B11	Lispro	2	Citrate 9.3 mM	23

[000735] The pharmacodynamic results obtained with the formulations described in examples B2 and B11 are presented in figure 13. According to the invention, the analysis of these curves shows that the formulation of example B11 comprising compound 2 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B11, glucose Tmin = 32 ± 10 min) makes it possible to obtain more rapid action than that obtained with the Humalog® commercial formulation of example B2 (curve plotted with the triangles corresponding to example B2, glucose Tmin = 41 ± 21 min).

[000736] The pharmacokinetic results obtained with the formulations described in examples B2 and B11 are presented in figure 14. According to the invention, the analysis of these curves shows that the formulation of example B11 comprising compound 2 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B11, insulin Tmax = 13 ± 5 min) induces more rapid absorption of the lispro insulin than that of the Humalog® commercial formulation of example B2 (curve plotted with the triangles corresponding to example B2, insulin Tmax = 22 ± 13 min).

C8: Pharmacodynamic and pharmacokinetic results for the insulin solutions of examples B1 and B38

Example	Insulin	Compound	Polyanionic compound	Number of pigs
B1	Aspart	-	-	37
B38	Human	2	Citrate 9.3 mM	31

[000737] The pharmacodynamic results obtained with the formulations described in examples B1 and B38 are presented in figure 15. The analysis of these curves shows that the formulation based on human insulin of example B38 comprising compound 2 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B102, glucose Tmin = 47 ± 30 min) makes it possible to obtain similar action to that obtained with the aspart insulin commercial formulation (Novolog®) of example B1 (curve plotted with the triangles corresponding to example B1, glucose Tmin = 47 ± 15 min).

[000738] The pharmacokinetic results obtained with the formulations described in examples B1 and B38 are presented in figure 16. The analysis of these curves shows that the formulation of example B38 comprising compound 2 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B38, insulin Tmax = 22 ± 21 min) induces human insulin absorption similar to that obtained with the aspart insulin commercial formulation (Novolog®) of example B1 (curve plotted with the triangles corresponding to example B1, insulin Tmax = 19 ± 12 min).

[000739] Since the time parameters for the aspart insulin (Novolog®) between examples C5 and C8 are similar, it may be deduced by extrapolation that the formulation of example B38 induces acceleration of the lowering of glycemia and of the absorption of human insulin relative to the commercial formulation of human insulin (example B3).

C9: Pharmacodynamic and pharmacokinetic results for the insulin solutions of examples B1 and B53

Example	Insulin	Compound	Polyanionic compound	Number of pigs
B1	Aspart	-	-	12
B53	Human	Compound 8	Citrate 9.3 mM	8

[000740] The pharmacodynamic results obtained with the formulations described in examples B1 and B53 are presented in figure 17. The analysis of these curves shows that the formulation based on human insulin of example B53 comprising compound 8 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B53, glucose Tmin = 63 ± 36 min) makes it possible to obtain action virtually as rapid as

that obtained with the aspart insulin commercial formulation (Novolog®) of example B1 (curve plotted with the triangles corresponding to example B1, glucose Tmin = 53 ± 19 min).

[000741] The pharmacokinetic results obtained with the formulations described in examples B1 and B53 are presented in figure 18. The analysis of these curves shows that the formulation of example B53 comprising compound 8 and citrate at 9.3 mM as excipients (curve plotted with the squares corresponding to example B53, insulin Tmax = 19 ± 12 min) induces human insulin absorption similar to that obtained with the aspart insulin commercial formulation (Novolog®) of example B1 (curve plotted with the triangles corresponding to example B1, insulin Tmax = 19 ± 6 min).

[000742] Since the time parameters for the aspart insulin (Novolog®) between examples C5 and C9 are similar, it may be deduced by extrapolation that the formulation of example B53 induces acceleration of the lowering of glycemia and of the absorption of human insulin relative to the commercial formulation of human insulin (example B3).

D Circular dichroism

D1: Association state of lispro insulin evaluated by circular dichroism in the presence of compound 1

[000743] Circular dichroism makes it possible to study the secondary and quaternary structure of insulin. The insulin monomers are organized as dimers and as hexamers. The hexamer is the physically and chemically most stable form of insulin. Two hexameric forms exist, the R6 form and the T6 form. Lispro insulin has a strong CD signal at 251 nm characteristic of the R6 hexameric form (most stable form). Loss of the CD signal at 251 nm is linked to destabilization of the hexamer (and thus the first sign of transformation of the hexamer into dimer).

[000744] EDTA and the EDTA/citrate mixture completely destructure the R6 form of lispro insulin (figure 11). EDTA thus has a pronounced effect on the hexamer.

[000745] In contrast, citrate alone, compound 1 alone, and also the mixture compound 1/citrate and compound 1/polyanionic compound 1, have virtually no impact on the CD signal at 251 nm. These compounds therefore have virtually no impact on the R6 structure of the hexamer and, all the less so, on the hexameric structure.

D2: Association state of human insulin evaluated by circular dichroism in the presence of compound 1

[000746] Circular dichroism makes it possible to study the secondary and quaternary structure of insulin. The insulin monomers are organized as dimers and as hexamers. The hexamer is the physically and chemically most stable form of insulin. The CD signal at

275 nm is characteristic of the hexameric form of insulin (hexamer signal at about -300°, signal for the dimer between -200° and -250°, and signal for the monomer below -200°). Loss of the CD signal at 275 nm is therefore characteristic of destabilization of the hexamer into dimers or monomers.

[000747] EDTA and the EDTA/citrate combination have a very pronounced impact on the hexameric structure of human insulin (total dissociation of the hexamer into dimers, figure 12). In contrast, citrate alone, compound 1 alone, the polyanionic compound 1 alone and also the compound 1/citrate and compound 1/polyanionic compound 1 combinations have no impact on the hexameric structure of human insulin. Unlike EDTA, the human insulin formulations comprising compound 1 and citrate or the polyanionic compound 1 do not show any dissociation of the human insulin hexamer.

D3: Association state of lispro insulin evaluated by circular dichroism in the presence of compounds 1 to 11

[000748] Circular dichroism makes it possible to study the secondary and quaternary structure of insulin. The insulin monomers are organized as dimers and as hexamers. The hexamer is the physically and chemically most stable form of insulin. Two hexameric forms exist, the R6 form and the T6 form. Lispro insulin has a strong CD signal at 251 nm characteristic of the R6 hexameric form (most stable form). Loss of the CD signal at 251 nm is linked to destabilization of the hexamer (and thus the first sign of transformation of the hexamer into dimer). The results obtained are presented in figure 19. This figure describes on the x-axis:

- A: lispro insulin (100 IU/mL)
- B: lispro insulin + 7.3 mg/mL of compound 2
- C: lispro insulin + 7.3 mg/mL of compound 2 + citrate at 9.3 mM
- D: lispro insulin + 7.3 mg/mL of compound 1
- E: lispro insulin + 7.3 mg/mL of compound 1 + citrate at 9.3 mM
- F: lispro insulin + 7.3 mg/mL of compound 3
- G: lispro insulin + 7.3 mg/mL of compound 3 + citrate at 9.3 mM
- H: lispro insulin + 7.3 mg/mL of compound 4
- I: lispro insulin + 7.3 mg/mL of compound 4 + citrate at 9.3 mM
- J: lispro insulin + 7.3 mg/mL of compound 5
- K: lispro insulin + 7.3 mg/mL of compound 5 + citrate at 9.3 mM
- L: lispro insulin + 7.3 mg/mL of compound 6
- M: lispro insulin + 7.3 mg/mL of compound 6 + citrate at 9.3 mM
- N: lispro insulin + 7.3 mg/mL of compound 7
- O: lispro insulin + 7.3 mg/mL of compound 7 + citrate at 9.3 mM
- P: lispro insulin + 7.3 mg/mL of compound 8

- Q: lispro insulin + 7.3 mg/mL of compound 8 + citrate at 9.3 mM
- R: lispro insulin + 7.3 mg/mL of compound 9
- S: lispro insulin + 7.3 mg/mL of compound 9 + citrate at 9.3 mM
- T: lispro insulin + 7.3 mg/mL of compound 10
- U: lispro insulin + 7.3 mg/mL of compound 10 + citrate at 9.3 mM
- V: lispro insulin + 7.3 mg/mL of compound 11
- W: lispro insulin + 7.3 mg/mL of compound 11 + citrate at 9.3 mM

and on the y-axis the circular dichroism signal at 251 nm ($deg.cm^2.dmol^{-1}$).

[000749] Compounds 1 to 11 alone and also compounds 1 to 11 in combination with citrate have no impact on the CD signal at 251 nm for lispro insulin. Compounds 1 to 11 therefore have no impact on the R6 structure of the hexamer and, all the less so, on the hexameric structure of lispro insulin.

D4: Association state of human insulin evaluated by circular dichroism in the presence of compounds 1 to 11

[000750] Circular dichroism makes it possible to study the secondary and quaternary structure of insulin. The insulin monomers are organized as dimers and as hexamers. The hexamer is the physically and chemically most stable form of insulin. The CD signal at 275 nm is characteristic of the hexameric form of insulin (hexamer signal at about -300°, signal for the dimer between -200° and -250°, and signal for the monomer below -200°). Loss of the CD signal at 275 nm is therefore characteristic of destabilization of the hexamer into dimers or monomers. The results obtained are presented in figure 20. This figure describes on the x-axis:

[000751] A: human insulin (100 IU/mL)

[000752] B: human insulin + 7.3 mg/mL of compound 2

[000753] C: human insulin + 7.3 mg/mL of compound 2 + citrate at 9.3 mM

[000754] D: human insulin + 7.3 mg/mL of compound 1

[000755] E: human insulin + 7.3 mg/mL of compound 1 + citrate at 9.3 mM

[000756] F: human insulin + 7.3 mg/mL of compound 3

[000757] G: human insulin + 7.3 mg/mL of compound 3 + citrate at 9.3 mM

[000758] H: human insulin + 7.3 mg/mL of compound 4

[000759] I: human insulin + 7.3 mg/mL of compound 4 + citrate at 9.3 mM

[000760] J: human insulin + 7.3 mg/mL of compound 5

[000761] K: human insulin + 7.3 mg/mL of compound 5 + citrate at 9.3 mM

[000762] L: human insulin + 7.3 mg/mL of compound 6

[000763] M: human insulin + 7.3 mg/mL of compound 6 + citrate at 9.3 mM

[000764] N: human insulin + 7.3 mg/mL of compound 7

[000765] O: human insulin + 7.3 mg/mL of compound 7 + citrate at 9.3 mM

[000766] P: human insulin + 7.3 mg/mL of compound 8

[000767] Q: human insulin + 7.3 mg/mL of compound 8 + citrate at 9.3 mM

[000768] R: human insulin + 7.3 mg/mL of compound 9

[000769] S: human insulin + 7.3 mg/mL of compound 9 + citrate at 9.3 mM

[000770] T: human insulin + 7.3 mg/mL of compound 10

[000771] U: human insulin + 7.3 mg/mL of compound 10 + citrate at 9.3 mM

[000772] V: human insulin + 7.3 mg/mL of compound 11

[000773] W: human insulin + 7.3 mg/mL of compound 11 + citrate at 9.3 mM

and on the y-axis the circular dichroism signal at 275 nm ($deg.cm^2.dmol^{-1}$).

[000774] Compounds 1 to 11 alone and also compounds 1 to 11 in combination with citrate have no impact on the CD signal at 275 nm for human insulin. Compounds 1 to 11 therefore have no impact on the hexameric structure of human insulin.

E Dissolution of human insulin and insulin analogs at the isoelectric point

E1. Dissolution of human insulin at its isoelectric point

[000775] Human insulin has an isoelectric point at 5.3. At this pH of 5.3, human insulin precipitates. A test demonstrating the formation of a complex of human insulin with the various compounds is performed at the isoelectric point. If an interaction exists, it is possible to dissolve the insulin at its isoelectric point.

[000776] A 200 IU/mL human insulin solution is prepared. Solutions of compounds at different concentrations (8, 30 or 100 mg/mL) in water are prepared. An equivolume (50/50) mixture between the human insulin solution and the solution of compound is prepared to lead to a solution containing 100 IU/mL of human insulin and the desired concentration of compound (4, 15 or 50 mg/mL). The pH of the various solutions is adjusted to pH 5.3 by adding 200 mM acetic acid.

[000777] The appearance of the solution is documented. If the solution is turbid, the compound at the test concentration does not allow dissolution of the human insulin. If the solution is translucent, the compound allows dissolution of the human insulin at the test concentration. In this way, the concentration of compound required to dissolve the human insulin at its isoelectric point may be determined. The lower this concentration, the greater the affinity of the compound for human insulin.

[000778] The results obtained are presented in Table 3. The results show that the compounds and the polysaccharides do not have the same properties in terms of human insulin dissolution.

Compounds (examples) or Polysaccharides (counterexamples)	Dissolution of human insulin at 100 IU/mL with the compound at 4 mg/mL	Dissolution of human insulin at 100 IU/mL with the compound at 15 mg/mL	Dissolution of human insulin at 100 IU/mL with the compound at 50 mg/mL
Counterexamples			
Polysaccharide 1	Yes	Yes	Yes
Polysaccharide 4	Yes	Yes	Yes
Polysaccharide 3	Yes	Yes	Yes
Polysaccharide 2	Yes	Yes	Yes
Polysaccharide 5	Yes	Yes	Yes
Examples			
Compound 1	No	No	Yes
Compound 2	No	No	Yes
Compound 3	No	No	Yes
Compound 4	No	No	Yes
Compound 6	No	No	Yes
Compound 8	No	No	Yes
Compound 9	No	No	Yes
Compound 10	No	No	Yes

Table 3

E2. Dissolution of lispro insulin at its isoelectric point

[000779] Lispro insulin has an isoelectric point at 5.3. At this pH, lispro insulin precipitates. A test demonstrating the formation of a complex of lispro insulin with the various compounds is performed at the isoelectric point. If an interaction exists, it is possible to dissolve the lispro insulin at its isoelectric point.

[000780] The commercial formulation of lispro insulin (Humalog®) is dialyzed against 1 mM PO_4 buffer (pH 7). After dialysis, the lispro insulin concentration is about 90 IU/mL. The lyophilized compound is weighed out and dissolved in the lispro insulin solution to lead to formulations containing lispro insulin at 90 IU/mL and the compound at the desired concentrations (4, 15 or 50 mg/mL). The pH of the various solutions is adjusted to pH 5.3 by adding 200 mM acetic acid.

[000781] The appearance of the solution is documented. If the solution is turbid, the compound at the test concentration does not allow dissolution of the lispro insulin. If the solution is translucent, the compound allows dissolution of the lispro insulin at the test concentration. In this way, the concentration of compound required to dissolve the lispro

insulin at its isoelectric point may be determined. The lower this concentration, the greater the affinity of the compound for the lispro insulin.

[000782] The results obtained are presented in Table 4. The results show that the compounds and the polysaccharides do not have the same properties in terms of lispro insulin dissolution.

Compounds (examples) or Polysaccharides (counterexamples)	Dissolution of lispro insulin at 90 IU/mL with the compound at 4 mg/mL	Dissolution of lispro insulin at 90 IU/mL with the compound at 15 mg/mL	Dissolution of lispro insulin at 90 IU/mL with the compound at 50 mg/mL
Counterexamples			
Polysaccharide 1	Yes	Yes	Yes
Polysaccharide 3	Yes	Yes	Yes
Polysaccharide 2	Yes	Yes	Yes
Examples			
Compound 1	No	No	Yes
Compound 2	No	No	Yes
Compound 3	No	No	Yes

Table 4

F Interaction with albumin

F1: In order to determine the interactions between the various polysaccharides or compounds and a model protein such as albumin, a Centricon test (membrane with a cut-off threshold of 50 kDa) was performed. A solution of polysaccharide or of compound at 7.3 mg/mL was diluted three-fold in a solution of BSA (bovine serum albumin) at 20 mg/mL in PBS (concentration in the mixture: 2.43 mg/mL of polysaccharide or of compound, 13.3 mg/mL of albumin and about 100 mM of salts).

[000783] This mixture was centrifuged on a Centricon to make about half the volume pass through the membrane. The albumin is quantitatively retained on the Centricon membrane. The polysaccharides and compounds analyzed alone pass in large majority through the membrane (for the polysaccharides having the largest molar masses, about 20% of the polysaccharide is retained).

[000784] After centrifugation, the polysaccharide or compound is assayed by UV in the filtrate. The percentage of polysaccharide or compound bound to the albumin is calculated via the following equation:

[000785] (1-[polysaccharide or compound in the filtrate in the presence of albumin]/[polysaccharide or compound in the filtrate in the absence of albumin])*100

[000786] The results obtained are presented in Table 5. It is very clearly observed that the polysaccharides of molar mass 5-15 kDa are strongly retained by the albumin in this test. In contrast, the compounds of the invention of lower molar mass are markedly less retained by the albumin in this test.

Polysaccharide or Compound	**% Polysaccharide or % Compound bound to BSA**
Counterexamples	
Polysaccharide 4	97%
Polysaccharide 1	95%
Polysaccharide 3	77%
Polysaccharide 5	86%
Polysaccharide 2	82%
Examples	
Compound 2	21%
Compound 1	20%
Compound 3	27%
Compound 4	24%
Compound 5	24%
Compound 6	26%
Compound 7	27%
Compound 8	27%
Compound 9	43%
Compound 11	35%

Table 5

Claims

1. A composition in aqueous solution, comprising insulin in hexameric form, at least one substituted anionic compound and a polyanionic compound:

- said substituted anionic compound being chosen from substituted anionic compounds, in isolated form or as a mixture, consisting of a backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from the group consisting of hexoses, in cyclic form or in open reduced form, wherein they are substituted with:

a) at least one substituent of general formula I:

$$-[R_1]_a-[AA]_m \quad \text{Formula I}$$

- the substituents being identical or different when there are at least two substituents, in which:
- the radical -[AA]- denotes an amino acid residue,
- the radical -R_1- being:
  - either a bond and then a = 0 and the amino acid residue -[AA] is directly linked to the backbone via a function G,
  - or a C2 to C15 carbon-based chain, and then a = 1, optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function before the reaction with the amino acid, said chain forming with the amino acid residue -[AA] an amide function, and is attached to the backbone by means of a function F resulting from a reaction between a hydroxyl function borne by the backbone and a function or substituent borne by the precursor of the radical -R_1-,
- F is a function chosen from ether, ester and carbamate functions,
- G is a carbamate function,
- m is equal to 1 or 2,
- the degree of substitution of the saccharide units, j, in $-[R_1]_a-[AA]_m$ being strictly greater than 0 and less than or equal to 6, $0 < j \leq 6$

b) and, optionally, one or more substituents $-R'_1$,

- the substituent -R'_1 being a C2 to C15 carbon-based chain, which is optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at

least one acid function in the form of an alkali metal cation salt, said chain being linked to the backbone via a function F' resulting from a reaction between a hydroxyl function or a carboxylic acid function borne by the backbone and a function or substituent borne by the precursor of the substituent -R'_1,

- F' is an ether, ester or carbamate function,
- the degree of substitution of the saccharide units, i, in -R'_1, being between 0 and 6-j, $0 \leq i \leq 6-j$, and
- F and F' are identical or different,
- F and G are identical or different,
- $i+j \leq 6$,
- -R'_1 is identical to or different from $-R_1-$,
- the free salifiable acid functions borne by the substituent -R'_1 are in the form of alkali metal cation salts,
- said glycoside bonds, which may be identical or different, being chosen from the group consisting of glycoside bonds of (1,1), (1,2), (1,3), (1,4) or (1,6) type, in an alpha or beta geometry,

and

- said polyanionic compound being a non-polymeric polyanionic (NPP) compound whose affinity for zinc is less than the affinity of insulin for zinc and whose dissociation constant Kd_{Ca} =[NPP compound]^r[Ca^{2+}]^s/[(NPP compound)^r-(Ca^{2+})^s] is less than or equal to $10^{-1.5}$.

2. The composition as claimed in claim 1, wherein the anionic molecule is chosen from the group consisting of polycarboxylic acids and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

3. The composition as claimed in claim 2, wherein the polycarboxylic acid is chosen from the group consisting of citric acid and tartaric acid, and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

4. The composition as claimed in claim 1, wherein the anionic molecule is chosen from the group consisting of polyphosphoric acids and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

5. The composition as claimed in claim 4, wherein the polyphosphoric acid is triphosphate and the Na^+, K^+, Ca^{2+} or Mg^{2+} salts thereof.

6. The composition as claimed in any one of the preceding claims, wherein the polyanionic compound is a compound consisting of a saccharide backbone formed from a

discrete number of saccharide units obtained from a disaccharide compound chosen from the group consisting of trehalose, maltose, lactose, sucrose, cellobiose, isomaltose, maltitol and isomaltitol.

7. The composition as claimed in any one of the preceding claims, wherein the insulin is a human insulin.

8. The composition as claimed in one of claims 1 to 6, wherein the insulin is an insulin analog.

9. The composition as claimed in claim 8, wherein the insulin analog is chosen from the group consisting of the insulin lispro (Humalog®), the insulin aspart (Novolog®, Novorapid®) and the insulin glulisine (Apidra®).

10. The composition as claimed in claim 8, wherein the insulin analog is the insulin lispro (Humalog®).

11. The composition as claimed in any one of the preceding claims, wherein the substituted anionic compound/insulin mass ratio is between 0.5 and 10.

12. The composition as claimed in any one of the preceding claims, wherein the concentration of substituted anionic compound is between 1.8 and 36 mg/mL.

13. The composition as claimed in any one of the preceding claims, wherein the substituted anionic compound is chosen from substituted anionic compounds, in isolated form or as a mixture, consisting of a saccharide backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from hexoses, in cyclic form or in open reduced form, wherein they are substituted with:

a) at least one substituent of general formula I:

$$-[R_1]_a-[AA]_m \qquad \text{Formula I}$$

- the substituents being identical or different when there are at least two substituents, in which:
- the radical -[AA]- denotes an amino acid residue,
- the radical -R_1- being:

either a bond and then a = 0 and the amino acid residue -[AA] is directly linked to the backbone via a function G,

or a C2 to C15 carbon-based chain, and then a = 1, optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function before the reaction with the amino acid, said chain forming with the amino acid residue -[AA] an amide function, and is attached to the backbone by means of a function F resulting from a reaction between a hydroxyl function borne by the backbone and a function or substituent borne by the precursor of the radical -R_1-,

- F is a function chosen from ether, ester and carbamate functions,
- G is a carbamate function,
- m is equal to 1 or 2,
- the degree of substitution of the saccharide units, j, in $-[R_1]_a-[AA]_m$ being strictly greater than 0 and less than or equal to 6, $0 < j \leq 6$

b) and, optionally, one or more substituents $-R'_1$,

- the substituent $-R'_1$ being a C2 to C15 carbon-based chain, which is optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and at least one acid function in the form of an alkali metal cation salt, said chain being linked to the backbone via a function F' resulting from a reaction between a hydroxyl function or a carboxylic acid function borne by the backbone and a function or substituent borne by the precursor of the substituent $-R'_1$,
- F' is an ether, ester or carbamate function,
- the degree of substitution of the saccharide units, i, in $-R'_1$, being between 0 and 6-j, $0 \leq i \leq 6-j$, and
- F and F' are identical or different,
- F and G are identical or different,
- $i+j \leq 6$,
- $-R'_1$ is identical to or different from $-R_1-$,
- the free salifiable acid functions borne by the substituent $-R'_1$ are in the form of alkali metal cation salts,
- said glycoside bonds, which may be identical or different, being chosen from the group consisting of glycoside bonds of (1,1), (1,2), (1,3), (1,4) or (1,6) type, in an alpha or beta geometry.

14. The composition as claimed in any one of claims 1 to 8, wherein the polyanionic compound is chosen from the group consisting of anionic molecules, anionic polymers and compounds consisting of a backbone formed from a discrete number u of between 1 and 3 ($1 \leq u \leq 3$) of identical or different saccharide units, linked via identical or different glycoside bonds naturally bearing carboxyl groups or substituted with carboxyl groups.

15. A pharmaceutical formulation comprising a compound as claimed in any one of the preceding claims.

16. The pharmaceutical formulation as claimed in claim 11, wherein the insulin concentration is between 240 and 3000 µM (40 to 500 IU/mL).

17. The pharmaceutical formulation as claimed in claim 12, wherein the insulin concentration is between 600 and 1200 µM (100 and 200 IU/mL).

18. The use of at least one functionalized anionic compound consisting of a backbone formed from a discrete number u of between 1 and 3 ($1 \leq u \leq 3$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from the group consisting of hexoses, in cyclic form or in open reduced form, said compound comprising partially substituted carboxyl functional groups, the unsubstituted carboxyl functional groups being salifiable, to prepare an insulin pharmaceutical formulation which makes it possible, after administration, to accelerate the passage of the insulin into the blood and to reduce the glycemia more rapidly when compared with a formulation free of substituted anionic compound in combination with at least said polyanionic compound being a non-polymeric polyanionic (NPP) compound whose affinity for zinc is less than the affinity of insulin for zinc and whose dissociation constant Kd_{Ca} $=[\text{NPP compound}]_r\ [Ca^{2+}]^s/[(\text{NPP compound})^r\text{-}(Ca^{2+})^s]$ is less than or equal to $10^{-1.5}$.

19. The use as claimed in claim 14, wherein the functionalized anionic compound is in a mixture with a polyanionic compound.

20. The use as claimed in claim 14 or 15, wherein the substituted anionic compound is chosen from substituted anionic compounds consisting of a saccharide backbone formed from a discrete number u of between 1 and 8 ($1 \leq u \leq 8$) of identical or different saccharide units, linked via identical or different glycoside bonds, said saccharide units being chosen from hexoses, in cyclic form or in open reduced form, wherein:

a) they are randomly substituted with:

- at least one substituent of general formula I:

$$-[R_1]_a-[AA]_m \qquad \text{Formula I}$$

- the substituents being identical or different when there are at least two substituents, in which:

- the radical –[AA]– denotes an amino acid residue, said amino acid being chosen from the group consisting of phenylalanine, alpha-methylphenylalanine, 3,4-dihydroxyphenylalanine, tyrosine, alpha-methyltyrosine, O-methyltyrosine, alpha-phenylglycine, 4-hydroxyphenylglycine and 3,5-dihydroxyphenylglycine, and the alkali metal cation salts thereof, said derivatives being in L or D absolute configuration, –[AA]– is attached to the backbone of the molecule via a linker arm $–R_1–$ or directly attached to the backbone via a function G,
- $–R_1–$ being:
  - either a bond G, and then a = 0,
  - or a C1 to C15 carbon-based chain, and then a = 1, which is optionally substituted and/or comprising at least one heteroatom chosen from O, N and S and bearing at least one acid function before the reaction with the amino acid, said chain forming with the amino acid residue -[AA] an amide bond, and is attached to the saccharide backbone via a function F resulting from a reaction between a hydroxyl function borne by the backbone and a function borne by the precursor of R_1,
- F is an ether, ester or carbamate function,
- G is an ester or carbamate function,
- m is equal to 1 or 2,
- the degree of substitution, j, in $–[R_1]_a–[AA]_m$ being strictly greater than 0 and less than or equal to 6, $0 < j \leq 6$,

and, optionally,

- one or more substituents $–R'_1$
- $-R'_1$ being a C2 to C15 carbon-based chain, which is optionally substituted and/or comprising at least one heteroatom (such as O, N and S) and bearing at least one acid function in the form of an alkali metal cation salt, said chain being attached to the saccharide backbone via a function F' resulting from a reaction between a hydroxyl function borne by the backbone and a function borne by the precursor of $-R'_1$,
- F' is an ether, ester or carbamate function,
- the degree of substitution, i, in $-R'_1$, being between 0 and 6-j, $0 \leq i \leq 6-j$, and
- $-R'_1-$ is identical to or different from $–R_1$,
- F and F' are identical or different,
- F' and G are identical or different,
- the free salifiable acid functions are in the form of alkali metal cation salts,

b) said glycoside bonds, which may be identical or different, being chosen from the group consisting of glycoside bonds of (1,1), (1,2), (1,3), (1,4) or (1,6) type, in an alpha or beta geometry,

c) $i + j \leq 6$.

21. The use as claimed in either of claims 15 and 16, wherein the polyanionic compound is chosen from the group consisting of anionic molecules, anionic polymers and compounds consisting of a backbone formed from a discrete number u of between 1 and 3 ($1 \leq u \leq 3$) of identical or different saccharide units, linked via identical or different glycoside bonds naturally bearing carboxyl groups or substituted with carboxyl groups.