New insulin analogues of prolonged activity

The subjects of the invention are new biosynthetic analogues of recombined human insulin of prolonged therapeutic activity, which may find use in prophylaxis and treatment of diabetes mellitus.

Insulin and its various derivatives are used in large amounts in treatments of diabetes mellitus and are often manufactured on a large industrial scale. While there are many different known modified derivatives of insulin and many pharmaceutical preparations of diverse activity profiles, a drug is still sought, which would enable to maintain a constant level of glucose in a human organism for an extended period of time.

To achieve the effect of delayed and/or prolonged activity some preparations of normal human insulin contain specific additions, e.g. various amounts of protamin, a protein that forms an insoluble complex with insulin which forms deposits in subcutaneous tissues, and from which insulin is gradually released.

There are known various human insulin derivatives used in treatment of diabetes, which contain additional amino acids or have modified sequence of some amino acids. Changes of primary structure of insulin influence its secondary and tertiary structure, which affects protein's chemical and biological properties, and that in turn results in pharmacokinetic and pharmacodynamic effects. These changes are of different character, can lead to accelerated or delayed and prolonged activity of modified insulin. Active form of insulin is a monomer, which easily filters into blood after subcutaneous injection. It is known, that exogenous human insulin in solutions has hexameric form, which after application dissociates to dimers and subsequently to monomers before filtering into blood stream. One of insulin derivatives characterised by accelerated activity is lispro-insulin (Humalog®), in which the sequence of proline (28)-lysine (29) in chain B has been inverted. It makes difficult, from the sterical point, to form dimers of insulin in a solution. Second such a derivative is insulin in which proline in the position 28 of chain B has been replaced with aspartic acid. Such introduced negative charge lowers possibility of self-association of insulin monomers. Both these insulin derivatives are absorbed faster due to their structure.

Prolonged-activity recombined human insulin analogues are constructed by elongating chain B with alkaline amino acids or acylating ε-amino group in lysine in chain B with aliphatic acid of about a dozen carbon atoms.

Introduction of these extra alkaline amino acids changes some chemical or physical properties of insulin. The most important change is a shift of isoelectric point in respect to unmodified natural insulin from 5.4 to the range of about 5.5 to about 8.5, which results from introduction of superfluous positive charges into the molecule. In consequence solubility of these analogues in neutral water environment is reduced, and therefore necessity of using

slightly acidic environment for production of pharmaceutical preparations containing such modified insulin.

However, beside obvious advantages resulting from introduction of extra alkaline amino acids there is observed also disadvantageous reduction of stability of new analogues, stemming primarily from deamination of asparagine in position A21 occurring in acidic environment.

This issue is addressed by replacement of A21Asn with other amino acid, such as aspartic acid, glycine, alanine, threonine and others. One of such analogues is recombinant human insulin derivative in which in chain A asparagine(21) has been replaced with glycine(21) and to the C terminus of chain B have been attached two arginine residues. This is so-called glargine derivative of insulin, manufactured under the name Lantus (patent US 5.656.722).

In the course of our research it has been established, that a human insulin derivative, where to the C terminus of chain B have been attached residues of lysine (B31Lys) and arginine (B32Arg) shows biological activity that is similar to glargine derivative, which is already present on the market. Preliminary research performed on animals indicates, that this preparation, called lizarginsulin, is characterised by prolonged activity and a flat release profile mimicking secretion of natural insulin, and from a clinical point of view – reduction of nocturnal hypoglycaemias. Because of exceptional similarity to human insulin and also to proinsulin, there could be expected good research results, enabling gradual development of the drug candidate and its final commercialisation. It is crucial, that LysArg sequence at C terminus of chain B of human insulin is found in human proinsulin, and one should expect transformation of lizarginsulin into human insulin by present carboxypeptidase C. This means, that first metabolite of lizarginsulin in human organism can be human insulin of well known and acceptable characteristics, even in the case of exogenous hormone. There was performed extended pre-clinical research on rats, which confirmed prolonged activity of the new insulin analogue.

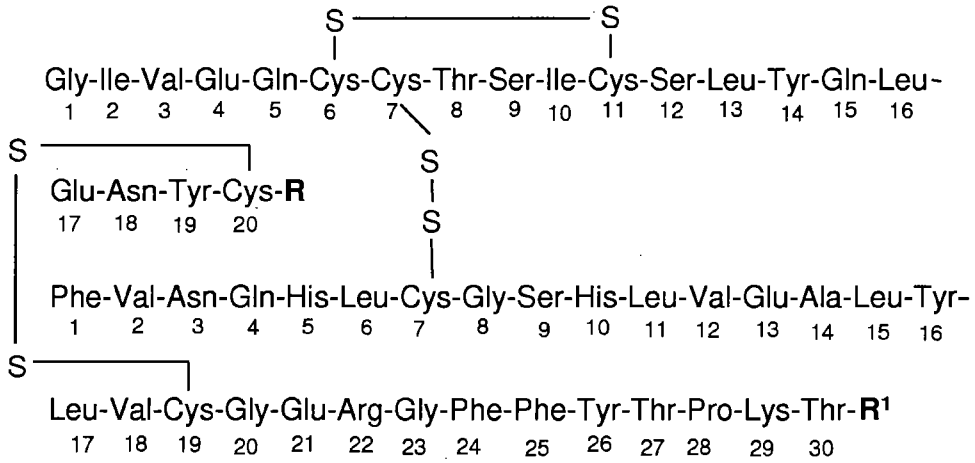
However it came out that this derivative apart of its advantageous biological activity is characterised by insufficient stability in acidic injection solutions. The main cause of insufficient stability, which manifests itself primarily as deamidation, is presence of asparagine residue at C terminus of chain A, where in acidic water environment can occur a deamidation autocatalysed by a proton from carboxyl group.

Therefore the aim of this invention is providing new analogues of insulin, which would be characterised by an adequate stability in acidic injection solutions (pH 3.5 – 5), and at the same time would possess the required biological activity. It is especially desirable that they would show characteristics of biological activity of natural insulin. It is also particularly important, that the start of activity of the new derivatives was practically immediate, just after

administration to the patient, with the ability of prolonged release of a part of the dose. This would enable to provide both accelerated and prolonged activity of the pharmaceutical preparation containing insulin analogues.

The above stated goal was unexpectedly achieved in this invention.

The basic aspect of the invention is an insulin derivative or its pharmaceutically acceptable salt containing two polypeptides constituting chain A and chain B, where amino acid sequence of chain A has been chosen from SEQ ID No 1-5, while amino acid sequence of chain B has been chosen from SEQ ID No 6-8. Preferred insulin derivative or its pharmaceutically acceptable salt according to the invention is characterised by being an analogue of recombined human insulin of isoelectric point 5 – 8.5 and formula 1:



Formula 1

where R denotes an NH_2 group or a group according to formula Asn-R^2, where R^2 denotes a neutral L-amino acid or an NH_2 group;

and R1 denotes B31Lys-B32Arg or B31Arg-B32Arg or B31Arg, where B3Asn may be alternatively replaced by other amino acid, advantageously by Glu.

Advantageously, the insulin derivative or its physiologically acceptable salt according to the invention is characterised by this, that:

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Gly and R^1 denotes B31Lys-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Ala and R^1 denotes B31Lys-B32Arg or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Ser and R^1 denotes B31Lys-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Thr and R^1 denotes B31Lys-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes group NH_2 and R^1 denotes B31Lys-B32Arg, or

R in the formula 1 denotes group NH_2 and R^1 denotes B31Lys-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Gly a R^1 denotes B31Arg-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Ala a R^1 denotes B31Arg-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Thr a R^1 denotes B31Arg-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Ser a R^1 denotes B31Arg-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes group NH_2 and R^1 denotes B31Arg-B32Arg, or

R in the formula 1 denotes group NH_2 a R^1 denotes B31Arg-B32Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Gly a R^1 denotes B31Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Ala a R^1 denotes B31Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Thr a R^1 denotes B31Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Ser a R^1 denotes B31Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes group NH_2 and R^1 denotes B31Arg, or

R in the formula 1 denotes group NH_2 a R^1 denotes B31Arg, or

R in the formula 1 denotes group of formula Asn-R^2, wherein R^2 denotes Gly, R^1 denotes B31Lys-B32Arg, and B3Asn has been replaced with B3Glu.

As described before, in the case of glargin the problem of low stability has been solved by replacing asparagine in the position A21 with glycine. Research, which aimed at obtaining an insulin analogue exhibiting prolonged activity and stability in acidic injection solutions as described in the invention, went in different direction. In order to block carboxyl group responsible for low stability, there were obtained new derivatives of lizarginsulin with carboxyl group in asparagine residue modified in different ways, using methods of genetic engineering and enzymatic transformation. As a result of the conducted research it unexpectedly turned out, that chemical and biological properties, similar to these of glargine and lizargine derivative, are exhibited by derivatives of human insulin of formula 1, where chain A has been elongated at C terminus with a residuum of neutral amino acid (A22) or

where carboxyl group of asparagine or cysteine at C terminus of chain A has been transformed into carboxyamid group, and to the C terminus of chain B there were attached residues of lysine and arginine (B31Lys-B32Arg), or two arginine residues (B31Arg-B32Arg), or one arginine residue (B31Arg). New analogues obtained in such a way are characterised by proper stability in acidic injection solutions (pH 3.5 – 5) and at the same time exhibit desired biological activity.

Introduced modification unexpectedly led to obtaining stable pharmaceutical compositions of insulin derivatives, at the same time preserving biological activity and causing a shift of isoelectric point to pH between 5 and 8, therefore reducing solubility of the new insulin derivative in physiological pH at the place of injection. This causes precipitation of insulin derivative microdeposit in subcutaneous tissue and subsequently slow release of the substance to the blood, which causes maintaining of theraupetical level by a prolonged time.

Properties of these compounds and their compositions have been confirmed by stability research and by researching their activity in animals with experimental diabetes. During these there was unexpectedly found remarkably prolonged effect of hypoglycaemic activity, which lasted also for a long time after stopping administration of the medicine, in contrast to what was observed for a reference commercially available insulin derivative of prolonged activity. This allows supposing, that properties of derivatives, which are the subject of the invention, will enable significantly less frequent administration of the medicine, which will increase effectiveness, safety and comfort of the patients therapy. It is also important, that start of activity of the new derivatives according to the invention is practically immediate, which means that these compounds unexpectedly exhibit characteristics of biological activity of known insulin analogues of both accelerated and prolonged activity.

Examples of insulin derivatives of formula 1 are such as, but not limited to, these exhibited below.

A22Gly	– human insulin –	B31LysB32Arg	(insulin GKR)
A22Ala	– human insulin –	B31LysB32Arg	(insulin AKR)
A22Ser	– human insulin –	B31LysB32Arg	(insulin SKR)
A22Thr	– human insulin –	B31LysB32Arg	(insulin TKR)
de(A21Asn)A20Cys-NH_2	– human insulin –	B31LysB32Arg	(insulin XKR)
A21Asn-NH_2	– human insulin –	B31LysB32Arg	(insulin ZKR)
A22Gly	– human insulin –	B3GluB31LysB32Arg	(insulin GEKR)
A22Gly	– human insulin –	B31ArgB32Arg	(insulin GRR)
A22Ala	– human insulin –	B31ArgB32Arg	(insulin ARR)
A22Ser	– human insulin –	B31ArgB32Arg	(insulin SRR)
A22Thr	– human insulin –	B31ArgB32Arg	(insulin TRR)

de(A21Asn)A20Cys-NH_2	– human insulin –	B31ArgB32Arg	(insulin XRR)
A21Asn-NH_2	– human insulin –	B31ArgB32Arg	(insulin ZRR)
A22Gly	– human insulin –	B31Arg	(insulin GR)
A22Ala	– human insulin –	B31Arg	(insulin AR)
A22Ser	– human insulin –	B31Arg	(insulin SR)
A22Thr	– human insulin –	B31Arg	(insulin TR)
de(A21Asn)A20Cys-NH_2	– human insulin –	B31Arg	(insulin XR)
A21Asn-NH_2	– human insulin –	B31Arg	(insulin ZR)

To simplify names of recombined human insulin analogues, which are the subject of the invention, they were assigned symbols which are composed of the name "insulin" and 2-4 capital letters of alphabet, which denote amino acid residues, which were added or which replaced these present in the parent particle of human insulin. In the most cases these letters are consistent with one-letter amino acid residues code recognised in the literature. Only for two residues, that do not occur naturally, there were used additional letters, namely "Z" and "X". In both cases the letter denotes a residue placed at C terminus of chain A, which where instead of the terminal COOH group there's $CONH_2$ group; letter "Z" denotes corresponding asparagine amide (that is A21Asn-NH_2), and letter "X" – cysteine amide (that is de(A21Asn)A20Cys-NH_2).

Insulin analogues of formula 1 were produced by a series of genetic manipulations using standard methods of genetic engineering.

To this end there were constructed modifications of the gene encoding recombined human proinsulin using genetic techniques such as for example site specific mutagenesis. Site-specific mutagenesis reaction has been performed using Stratagene kit (cat. no. 200518-5), as a template has been used plasmid DNA pIGALZUINS - p5/ZUINS or pIGTETZUINS – p6/ZUINS. Also any other DNA containing proper sequence encoding recombined human proinsulin or preproinsulin can be used as the template.

According to the invention, in the light of recognised terminology, recombined human proinsulin is understood as a polypeptide chain where chains A and B of human insulin are connected by dipeptide Lys-Arg or Arg-Arg, and the recombined preproinsulin – a combination of proinsulin and an additional leader polypeptide, for example ubiquitin, or SOD or their fragments.

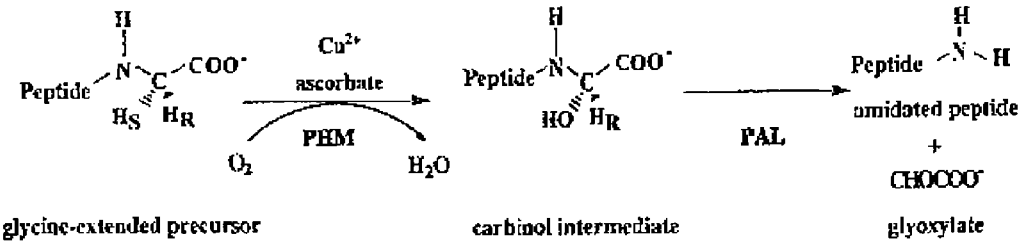
Reaction mixture was used to transform competent cells of a proper *Escherichia coli* strain, as for example *DH5α*, *DH5*, or *HB101*, however it is possible to use cells of other *E. coli* strains or cells of other microorganisms, or other known cell lines which can be used for expression of recombined proteins. Plasmid containing given modification of a gene encoding recombined human proinsulin was isolated and sequenced in order to verify correctness of nucleotide sequence. According to the variant of the invention, plasmid with

the modified gene encoding recombined human proinsulin was used to transform competent *E. coli DH5α* cells and bacteria were cultured in LB media with addition of selection antibiotic (0.01 mg/ml) in the volume of 500 ml, at temp. 37°C, 200 rpm for 18 h. Bacterial material was prepared for strain bank, samples in proportion 1:1 of bacteria culture and 40% glycerol were deposited at -70 °C.

Variants of recombined preproinsulin obtained by expression in *E. coli* strains were isolated in the form of inclusion bodies, after the cells had been disintegrated, and subsequently were subjected to standard processes of fusion proteins purification. Solution of hybrid protein with insulin analog obtained after renaturation was subjected to controlled treatment with tripsine, analogously to case of many methods known beforehand and described e.g. by Kemmlera et al. in J. Biol. Chem., Vol. 246, page 6786-6791 (1971) or patents US 6686177 and US 6100376. Obtained insulin analogues were subjected to the process of purification using known methods, mainly low-pressure chromatography, ultrafiltration and/or HPLC. The product was precipitated from sufficiently purified solution of insulin analogue.

In order to obtain derivatives containing at the C terminus of chain A residue A21Asn-NH_2 or A20Cys-NH_2, there were used α-amidating enzymes (α-AE), catalysing conversion of naturally appearing in living organisms prohormones, which are reaction substrates converted into active α-amid forms.

Enzyme PAM (peptidylglycine α-amidating monooxygenase) is a protease with dual activity, denoted as activity PHM (Peptidylglycine alpha-hydroxylating monooxygenase) and PAL (peptidylamidoglycolate lyase activity) (Diagram 1), which enables obtaining C terminal amide. It was investigated, that half of peptide hormones, such as oxytocin or vasopressin require achieving their optimal activity a C-terminal amid group. In this reaction the amid group originates from C-terminal gycine residue, which is here direct reaction precursor (Satani M., Takahashi K., Sakamoto H., Harada S., Kaida Y., Noguchi M.; Expression and characterization of human bifunctional peptidylglycine alpha-amidating monooxygenase. *Protein Expr Purif.* 2003 Apr; 28(2):293-302.; Miller D. A., Sayad K. U., Kulathila R., Beaudry G. A., Merkler D. J., Bertelsen A. H.; Characterization of a bifunctional peptidylglycine alpha-amidating enzyme expressed in Chinese hamster ovary cells. *Arch Biochem Biophys.* 1992 Nov 1; 298(2):380-8).



Precursor with Gly hydroxyl derivative glyoxylate

Diagram 1 Outline of α-amidation of a peptide by active PAM protease (according to Satani M., Takahashi K., Sakamoto H., Harada S., Kaida Y., Noguchi M.; Expression and characterization of human bifunctional peptidylglycine alpha-amidating monooxygenase. *Protein Expr Purif.* 2003 Apr; 28(2):293-302.).

PAM protease is a protein which is found inter alia in eukaryotic organisms of different length of amino acid chain. In this project there was used a protease originating from human organism (*Homo sapiens*), in which there are found 6 genes encoding proteins exhibiting activity of α-amidating protease.

The basic physicochemical property of recombined human insulin analogues of formula 1, which differentiates them from human insulin, is their value of isoelectric point, which has values from about 5 to about 8. This means good solubility of the compounds in solutions of acidic to slightly acidic pH. This property enabled preparation of composition – solutions of new insulin derivatives in acidic pH.

An aspect of the invention is also pharmaceutical composition characterised by this, that it contains effectively acting amount of insulin derivative according to the invention or its pharmaceutically acceptable salt, which are defined above. Favourably, the pharmaceutical composition according to the invention contains also from 10 to 50 μg/ml of zinc.

Consecutive aspect of the invention is also use of insulin derivative according to the invention or its pharmaceutically acceptable salt, which were defined above, to manufacture drug for treatment or prevention of diabetes.

In accordance with the above, the pharmaceutical composition, according to the invention, contains effectively acting amount of biosynthetic analogue of human insulin of formula 1 or its pharmacologically acceptable salt and auxiliary substances.

A salt of biosynthetic human insulin analogue according to the invention can be for example a salt of alkaline metal or ammonium salt.

Intended for administration composition according to the invention is prepared in the form of solution and contains: effectively acting amount of biosynthetic analogue of human insulin of formula 1 or its pharmacologically acceptable salt and auxiliary substances, such as: isotonic agents, preservatives agents, stabilizing agents, optionally buffering agents.

Amount of the active substance used in the composition according to the invention is about 1-1600, favourably 10-1200, especially favourably 10-500 u/ml. In case of each human insulin analogue, which is subject of this invention, by 1 unit (1u) is meant 1 auxiliary unit, containing the same number of moles of the analogue as 1 international unit of insulin, corresponding to 6 nMol (that is 6×10^{-9} Mol).

For pharmaceutical composition according to the invention pH value of the solution is from about 3.5 to about 5, favourably 4.0-4.5.

Generally, auxiliary substances in compositions according to the invention are the same substances that are used in preparations containing known recombined human insulin.

Isotonic substance according to the invention can be any substance, which allows obtaining solution isoosmotic in respect to human blood plasma. To typical isotonic agents used in pharmacy belong such substances as sodium chloride, mannitol, glycine, preferably glycerine. Favourable is use of glycerine.

Useful conserving agents to be used in composition according to the invention are compounds chosen from the group to which belongs m-cresole, phenol or their mixtures.

New derivatives, similarly to recombined normal human insulin, are stabilised by addition of zinc ions, introduced into the solution in the form of, among other, zinc chloride or oxide. Amount of the zinc can range from around 5 µg/ml to around 150 µg/ml.

A following example of a content of the composition containing derivatives of recombined human insulin according to the invention has been developed: 10-500 u/ml of biosynthetic analogue of human insulin of formula 1 or its pharmacologically acceptable salt, 16 mg/ml of glycerine, 2.7 - 3 mg/ml m-cresole, 10-50 µg/ml of zinc and water for injection to 1 ml.

To better explain the essence of the invention this description has been extended with a detailed discussion of examples of the invention's realisation, which encompasses also enclosed list of sequences and figures, of which:

Figure 1 presents structure of plasmid p5/ZUINSGly(22A) containing a gene encoding GKR protein of recombined insulin.

Figure 2 presents nucleotide and amino acid sequence of plasmid p5/ZUINSGly(22A).

Figure 3 presents structure of plasmid p6/ZUINSSer(22A) containing a gene encoding insulin SKR protein.

Figure 4 presents nucleotide and amino acid sequence of plasmid p6/ZUINSSer(22A).

Figure 5 presents influence of single dose administration of GKR insulin (in the dose of 5 u/kg of body mass on glucose concentration in blood of normoglycaemic rats, compared with preparation of Gensulin N. Average values ± SEM. Statistical significance **p<0.01: Insulin GKR vs. initial glucose concentration; ##p<0.01, #p<0.05: Gensulin N vs. initial glucose concentration; ^^p<0.01: Insulin GKR vs. Gensulin N.

Figure 6 presents influence of single dose administration of GKR insulin (in dose of 5u per kg of body mass) on glucose concentration in blood of rats with mild streptozotocin-induced diabetes (in comparison with Lantus preparation). 0 – fixed hyperglycaemia; control – physiological salt solution 10 µl/200 g bm. Statistical significance: ** $p < 0.01$, * $p < 0.05$ GKR vs. Lantus;

Figure 7 presents influence of single dose administration of GKR insulin (in doses of 2.5 u, 5u and 7.5 u per kg of body mass) on glucose concentration in blood of rats with severe streptozotocin-induced diabetes. 0 – fixed hyperglycaemia; control – physiological salt solution 10 µl/200 g bm. Statistical significance: ** $p < 0.01$ * $p < 0.05$ GKR 2,5 u vs control; ^^ $p < 0.01$ ^ $p < 0.05$ GKR 5 u vs control; ## $p < 0.01$ # $p < 0.05$ GKR 7.5 u vs control

Figure 8 presents influence of single dose administration of GKR insulin (in dose of 7.5u per kg of body mass) on glucose concentration in blood of rats with severe streptozotocin-induced diabetes (in comparison with Lantus preparation). 0 – fixed hyperglycaemia; control – physiological salt solution 10 µl/200 g bm. Statistical significance: ** $p < 0.01$, * $p < 0.05$ GKR vs. Lantus;

Figure 9 presents glucose concentration in blood of rats after multiple administrations of GKR insulin in doses of 5 u per kg of body mass in a model of mild streptozotocin-induced diabetes (in comparison with Lantus preparation); 0 – fixed hyperglycaemia; control – physiological salt solution10 µl/200 g bm.

Figure 10 presents glucose concentration in blood of rats in the period after stopping administration of GKR insulin in dose of 5 u per kg of body mass in a model of mild streptozotocin-induced diabetes (in comparison with Lantus preparation);

Figure 11 presents influence of single dose administration of GR insulin (in doses of 10 u per kg of body mass) on glucose concentration in blood of rats with moderate streptozotocin-induced diabetes compared with Lantus preparation. 0 – fixed hyperglycaemia; control – physiological salt 10 µl/200 g bm. 0 – fixed hyperglycaemia; control – physiological salt solution 10 µl/200 g bm. Statistical significance: ** $p < 0.01$, * $p < 0.05$ GR vs. Lantus;

Figure 12 presents influence of single dose administration of GEKR insulin (in dose of 10 u per kg of body mass) on glucose concentration in blood of rats with moderate streptozotocin-induced diabetes compared with Levemir preparation. 0 – fixed hyperglycaemia;

Example 1. Construction of p5/ZUINSGly(22A) plasmid and obtaining of a strain transformed with this plasmid.

To construct a gene encoding recombined INSGly(22A) proinsulin there was used p5/ZUINS plasmid, in which a DNA fragment encoding recombined insulin precursor is added to a modified gene of synthetic ubiquitin. In the ubiquitin gene arginine codons have been replaced with alanine codons and to the C terminus of ubiquitin gene there has been added aditional arginine codon. Peptide which constitutes part of ubiquitin is a carrier for insulin precursor, and is a condition for high efficiency of fusion protein synthesis in *E. coli*. The region encoding the modified fusion protein ubiquitin-human insulin is placed under control of *pms* (WO05066344 A2) promoter. The plasmid carries ampicillin resistance gene. For construction of p5/ZUINS vector there was used pIGAL1 plasmid, whose sequence deposited in Gene Bank has number AY424310.

The recombined INSGly(22A) proinsulin gene differs from the model human proinsulin gene in such a way, that it has attached additional GGT codon at C terminus of chain A. In result amino acid sequence of chain A is being elongated at position 22 with Gly – glycine – amino acid residue.

In order to modify the gene encoding human recombined proinsulin sequence by adding of GGT (Gly) codon at its C terminus, there were designed following primers for point mutagenesis reaction:

GLYG
5' AACTACTGCAAT**GGT**TAAGTCGACTCTAGC 3'
Gly STOP

GLYD
5' GTAGCTAGAGTCGACTTA**ACC**ATTGCAG 3'
Gly

The point mutagenesis reaction was carried out using Stratagene kit (catalogue no 200518-5). As the template there has been used plasmid DNA p5/ZUINS. *Escherichia coli* DH5 α competent cells were transformed with reaction mixture. Plasmid p5/ZUINSGly(22A) has been isolated and sequenced in order to verify presence of GGT nucleotides encoding glycine and the validity of plasmid sequence. Plasmid with the modified gene encoding recombined p5/ZUINSGly(22A) proinsulin has been used in transformation of competent *E. coli* DH5α cells which were subsequently cultivated for 18 hours in LB medium with addition of ampicillin (0.01 mg/ml) in the volume of 500 ml, at 37°C, 200 rpm. Bacteria material has been prepared for strain bank, samples containing 1:1 bacterial cultures and 40% glycerol have been deposited at -70 °C.

Obtained *Escherichia coli* strain constitutes the initial biological material in the process of obtaining GKR insulin via biosynthesis, according to Example 10.

Genetic construction of p5/ZUINSGly(22A) plasmid

Plasmid p5/ZUINSGly(22A) is 4775 base pairs long and is built of following regulatory sequences and genes:

- from 374 bp to 1234 bp there is ampicillin resistance gene AMP R,
- from 4158 bp to 4323 bp there is a region encoding *pms* promoter,
- from 4327 bp to 4554 bp there is a sequence encoding modified synthetic ubiquitin gene ZUBI,
- from 4558 bp to 4722 bp there is a sequence encoding the recombined INSGly(22A) proinsulin gene,
- from 4729 bp to 4775 bp there is a region encoding transcription terminator Ter.

Structure of p5/ZUINSGly(22A) plasmid containing the gene encoding recombined human insulin protein (GKR insulin) is shown schematically in Figure 1, and its nucleotide and amino acid sequence at Figure 2.

Example 2. Construction of p5/ZUINSGly(22A)Arg(31B) plasmid and obtaining a strain transformed with it.

In construction of recombined INSGly(22A)Arg(31B) proinsulin gene there was used p5/ZUINSGly(22A) plasmid. The recombined INSGly(22A)Arg(31B) gene is characterised by replacement of AAG (Lys) codon with CGT (Arg) codon at position 31 of chain B.

In order to modify the gene encoding sequence of recombined INSGly(22A) proinsulin there were designed following primers for point mutagenesis reaction:

ARGG
5' CTAAAACA**CGT**CGCGGCATCGTTGAACAG 3'
Arg

ARGD
5' CGATGCCGCG**ACG**TGTTTTAGGAGTGTAG 3'
Arg

Stratagene kit (cat. no 200518-5) has been used to conduct point mutagenesis reaction. Isolation, verification of validity of plasmid nucleotide sequence and obtaining *E.* coli DH5α bacteria with p5/ZUINSGly(22A)Arg(31B) plasmid have been performed as in Example 1.

Obtained *Escherichia coli* strain is the initial biological material in the process of manufacturing GR insulin via the biosynthesis according the Example 11.

Example 3. Construction of p5/ZUINSSer(22A)Arg(31B) plasmid and obtaining of a strain transformed with it

To construct a gene of recombined INSSer(22A)Arg(31B) proinsulin there was used p5/ZUINSGly(22A)Arg(31B) plasmid. The difference between the gene encoding recombined INSSer(22A)Arg(31B) proinsulin and the gene encoding recombined proinsulin INSGly(22A)Arg(31B) is a replacement of GGT (Gly) codon with TCT (Ser) codon at position 22 of chain A.

In order to modify the gene encoding the sequence of recombined INSGly(22A)Arg(31B) proinsulin by replacement of GGT (Gly) with TCT (Ser) codon at position 22 of chain A, there were designed following primers for point mutagenesis reaction:

SERG
5' CAAT**TCT**TAAGGATCCTCTAG 3'
Ser STOP

SERD
5' CTTA**AGA**ATTGCAGTAGTTCTCCAG 3'
Ser

Stratagene kit (cat. no 200518-5) has been used to conduct point mutagenesis reaction. Isolation, verification of validity of plasmid nucleotide sequence and obtaining *E.* coli DH5α bacteria with p5/ZUINSSer(22A)Arg(31B) plasmid have been performed as in Example 1.

Obtained *Escherichia coli* strain is the initial biological material in the process of manufacturing SR insulin via biosynthesis according to Example 12.

Example 4 Construction of p5/ZUINSAla(22A) plasmid and obtaining of a strain transformed with it.

To construct a gene of recombined INSAla(22A) proinsulin there has been used p5/ZUINS plasmid. The difference between the gene of recombined INSAla(22A) proinsulin and the model human proinsulin gene is addition of GCT codon to the C terminus of chain A of the former. In result the amino acid sequence of chain A is elongated at position 22 with Ala – alanine amino acid residue.

In order to modify the gene encoding the sequence of recombined human insulin by addition of GCT (Ala) codon at its C terminus, there were designed following primers for point mutagenesis:

ALAG
5' CAAT**GCT**TAAGGATCCTCTAG 3'
Ala STOP
ALAD
5' CTTA**AGC**ATTGCAGTAGTTCTCCAG 3'
Ala

Stratagene kit (cat. no 200518-5) has been used to conduct point mutagenesis reaction. Isolation, verification of validity of plasmid nucleotide sequence and obtaining *E.* coli DH5α bacteria with p5/ZUINSAla(22A) plasmid have been performed as in Example 1.

Obtained *Escherichia coli* strain is the initial biological material in the process of manufacturing AKR insulin via biosynthesis according to Example 13.

Example 5. Construction of p5/ZUINSGly(22A)Glu(3B) plasmid and obtaining of a strain transformed with it

To construct a gene of recombined p5/ZUINSGly(22A)Glu(3B) proinsulin there was used p5/ZUINSGly(22A) plasmid. The difference between the gene encoding recombined

INSGly(22A)Glu(3B) proinsulin and the gene encoding recombined INSGly(22A) proinsulin is a replacement of AAC (Asn) codon with GAA (Glu) codon at position 3 of chain B.

In order to modify the gene encoding the sequence of recombined INSGly(22A) proinsulin by replacement of AAC (Asn) with GAA (Glu) codon at position 3 of chain B, there were designed following primers for point mutagenesis reaction:

GLUG
5' GTC**GAA**CAGCACCTGTGTGGTTC 3'
Glu

GLUD
5' GCTGT**TC**GACAAAACGAGGACCTGC 3'
Glu

Stratagene kit (cat. no 200518-5) has been used to conduct point mutagenesis reaction. Isolation, verification of validity of plasmid nucleotide sequence and obtaining *E.* coli DH5α bacteria with p5/ZUINSGly(22A)Glu(31B) plasmid have been performed as in Example 1.

Obtained *Escherichia coli* strain is the initial biological material in the process of manufacturing GEKR insulin via biosynthesis according to Example 14.

In examples 1-5 as the plasmid hosts there have been used DH5α *E. coli* bacteria, but in described above, model realisation of the invention there can be used also other *E. coli* strains, for example DH5 or HB101.

Example 6. Construction of p6/ZUINSSer(22A) plasmid and obtaining of a strain transformed with it

To construct a gene encoding recombined INSSer(22A) proinsulin there was used p6/ZUINS plasmid, in which DNA fragment encoding precursor of recombined insulin is appended to modified gene encoding synthetic ubiquitin. In the ubiquitin-encoding gene arginine codons have been replaced with alanine codons and to the C terminus of ubiquitin gene there has been added an additional arginine codon. The peptide constituting part of ubiquitin is a carrier for insulin precursor, which conditions high efficiency of fusion protein expression in *E. coli*. The region encoding the modified ubiquitin-human insulin fusion protein is placed under control of *pms* promoter (WO05066344 A2). The plasmid carries tetracycline resistance gene. To construct p6/ZUINS vector there has been used p5/ZUINS plasmid.

The difference between the gene encoding recombined INSSer(22A) proinsulin and the model human proinsulin gene is that the former has appended additional TCT codon at C terminus of chain A. In result amino acid sequence of chain A is elongated at position 22 with Ser – serine amino acid residue.

In order to modify the gene encoding the sequence of recombined proinsulin by appending TCT (Ser) codon at its C terminus, there were designed following primers for point mutagenesis reaction:

SKRG
5' GAACTACTGCAAT**TCT**TAAGTCGA 3'

Ser STOP

SKRD
5' TAGAGTCGACTTA**AGA**ATTGCAGTA3'
Ser

Stratagene kit (cat. no 200518-5) has been used to conduct point mutagenesis reaction, as the template has been used p6/ZUINS plasmid DNA. *Escherichia coli* DH5α competent cells have been transformed with the reaction mixture. p6/ZUINSSer(22A) plasmid has been isolated and sequenced in order to verify presence of TCT nucleotides encoding serine and correctness of the plasmid sequence. The plasmid with the modified gene encoding p6/ZUINSSer(22A) proinsulin has been used to transform *E. coli* DH5α bacteria. Subsequently the bacteria were cultivated for 18 hours in LB media with addition of tetracycline (0.01 mg/ml) in 500 ml volume at 37°C, 200 rpm.

Bacteria material has been prepared for strain bank samples containing 1:1 bacterial cultures and 40% glycerol have been deposited at -70°C.

Obtained *Escherichia coli* strain constitutes initial biological material in the process of manufacturing SKR insulin via biosynthesis according to Example 15.

Genetic construction of p6/ZUINSSer(22A) plasmid

p6/ZUINSSer(22A) plasmid is 4911 base pairs long and is made of following regulatory sequences and genes:

- from 146 bp to 1336 bp there is a tetracycline resistance gene TET R,
- from 4304 bp to 4469 bp there is a region encoding *pms* promoter,
- from 4473 bp to 4703 bp there is a region encoding the gene encoding the modified synthetic ubiquitin; there are following modifications: replacement of arginine amino acid at positions 42, 54, 72, 74 in the ubiquitin gene with alanine and addition of arginine at position 77 which allows to remove the ubiquitin,
- from 4704 bp to 4868 bp there is a sequence encoding the gene encoding recombined INSSer(22A) proinsulin,
- from 4875 bp to 4911 bp there is a region encoding transcription terminator Ter.

Structure of p6/ZUINSSer(22A) plasmid containing the gene encoding recombined human insulin protein (SKR protein) is shown schematically in Figure 3, and its nucleotide and amino acid sequence in Fig. 4.

Example 7. Construction of p6/ZUINSGly(22A) plasmid and obtaining of a strain transformed with it.

To construct a gene encoding recombined INSGly(22A) proinsulin there was used p6/ZUINS plasmid, in which DNA fragment encoding precursor of recombined insulin is appended to modified gene encoding synthetic ubiquitin.

The difference between the gene encoding recombined INSGly(22A) proinsulin and the model human proinsulin gene is that the former has appended additional GGT codon at

C terminus of chain A. In result amino acid sequence of chain A is elongated at position 22 with Gly – glycine amino acid residue.

In order to modify the gene encoding the sequence of recombined human proinsulin by appending GGT (Gly) codon at its C terminus, there were designed following primers for point mutagenesis reaction:

GLYG
5' AACTACTGCAAT**GGT**TAAGTCGACTCTAGC 3'
Gly STOP

GLYD
5' GTAGCTAGAGTCGACTTA**ACC**ATTGCAG3'
Gly

Stratagene kit (cat. no 200518-5) has been used to conduct point mutagenesis reaction. Isolation, verification of validity of plasmid nucleotide sequence and obtaining *E.* coli DH5 bacteria with p6/ZUINSGly(22A) plasmid have been performed as in Example 6.

Obtained *Escherichia coli* strain constitutes initial biological material in the process of manufacturing GKR insulin via biosynthesis according to Example 16.

Example 8. Construction of p6/ZUINSGly(22A)Glu(3B) plasmid and obtaining of a strain transformed with it.

To construct a gene of recombined INSGly(22A)Glu(3B) proinsulin there has been used p6/ZUINSGly(22A) plasmid. The difference between the gene of recombined INSGly(22A)Glu(3B) proinsulin and the recombined INSGly(22A) proinsulin gene is replacement of AAC (Asn) codon with GAA (Glu) codon at position 3 of chain B.

In order to modify the gene encoding the sequence of recombined INSGly(22A) proinsulin by replacement of AAC (Asn) codon with GAA (Glu) codon at position 3 in chain B, there were designed following primers for point mutagenesis:

GLUG
5' GTC**GAA**CAGCACCTGTGTGGTTC 3'
Glu

GLUD-2
5' CACAGGTGCTG**TTC**GACAAAACGACC 3'
Glu

Stratagene kit (cat. no 200518-5) has been used to conduct point mutagenesis reaction. Isolation, verification of validity of plasmid nucleotide sequence and obtaining *E.* coli DH5 bacteria with p6/ZUINSGly(22A)Glu(31B) plasmid have been performed as in Example 6.

Obtained *Escherichia coli* strain is the initial biological material in the process of manufacturing GEKR insulin via biosynthesis according to Example 17.

Example 9. Construction of p6/ZUINSGly(22A)Arg(31B) plasmid and obtaining of a strain transformed with it

To construct a gene of recombined INSGly(22A)Arg(31B) proinsulin there has been used p6/ZUINSGly(22A) plasmid. The gene encoding recombined INSGly(22A)Arg(31B) proinsulin is characterised by this, that it has replaced AAG (Lys) codon with CGT (Arg) codon at position 31 of chain B.

In order to modify the gene encoding the sequence of recombined INSGly(22A) proinsulin there were designed following primers for point mutagenesis:

ARGG
5' CTAAAACA**CGT**CGCGGCATCGTTGAACAG 3'
Arg

ARGD
5' CGATGCCGCG**ACG**TGTTTTAGGAGTGTAG 3'
Arg

Stratagene kit (cat. no 200518-5) has been used to conduct point mutagenesis reaction. Isolation, verification of validity of plasmid nucleotide sequence and obtaining *E.* coli DH5 bacteria with p6/ZUINSGly(22A)Arg(31B) plasmid have been performed as in Example 6.

Obtained *Escherichia coli* strain is the initial biological material in the process of manufacturing GR insulin via biosynthesis according to Example 18.

Example 10. Manufacturing of GKR insulin

GKR insulin has been manufactured in a biosynthesis process realised in the classical way (inoculum, seed culture, production culture) using *Escherichia coli* strain with a DNA fragment encoding GKR insulin precursor obtained according to Example 1. Production cultivation has been conducted in 150 dm^3 fermentation tank for 20 hours at 37 °C, controlling pH, temperature, optical density, glucose concentration and aeration. In the fermentation conditions GKR analogue has been produced intracellulary in inclusion bodies. After the end of fermentation the fermentation broth has been concentrated and subsequently digested with lysosyme and bacterial cells have been subjected to disintegration. Obtained suspension has been diluted with water and after incubation with Triton centrifuged. Created raw deposit of inclusion bodies was initially purified, finally obtaining inclusion bodies homogenate.

The obtained homogenate has been dissolved (10-15 mg/cm^3) in the solution of sodium carbonate with addition of EDTA, subjected to renaturation and, for protection of lysine free amino groups, subjected to reversible process of citraconylation in a reaction with citraconic anhydride. The dissolved protein had been subjected to trypsine digestion in order to cleave the leader protein out and to cleave the insulin chains. In the result of trypsine activity there was obtained GKR insulin. The solution after digestion with trypsine has been subjected to purification with low pressure liquid chromatography on DEAE Sepharose FF gel, and subsequently diafiltration and concentration -- second low pressure liquid chromatography on Q Sepharose FF gel. Main fraction has been subjected to purification with high pressure

liquid chromatography on Kromasil-RPC8 100A 10µm gel. Main fraction has been concentration using dialysis to concentration of 30-40 mg/cm^3 and purified GKR insulin has been separated by crystallisation, using sodium citrate, zinc acetate, citric acid.

From one batch of inclusion bodies has been obtained about 5.4 g of crystallised GKR insulin of HPLC purity 97%.

The product's structure has been confirmed by following data:

- molecular mass determined by mass spectroscopy is equal to 6149 and conforms to the theoretical value (6149.1);
- peptide map: conforms;
- sequence and amino acid composition: conforming to theoretical.

Isoelectric point determined by capillary electrophoresis is 7.19.

Example 11. Manufacturing of GR insulin

Proceeding analogously to Example 10, using *Escherichia coli* strain with DNA fragment encoding GR insulin precursor, obtained in accordance with Example 2, there has been obtained from analogous batch of inclusion bodies 5.2 g of GR insulin of HPLC purity equal to 97.5%.

Product's structure has been confirmed by following data:

- molecular mass determined by mass spectroscopy equals 6021 and conforms to theoretical value (6020.9);
- peptide map: conforms,
- sequence and amino acid composition: conform to theoretical.

Isoelectric point: 6.39.

Example 12. Manufacturing of SR insulin

Proceeding analogously to Example 10, using *Escherichia coli* strain with DNA fragment encoding SR insulin precursor, obtained in accordance with Example 3, there has been obtained from analogous batch of inclusion bodies 5.5 g of SR insulin of HPLC purity equal to 97%.

Product's structure has been confirmed by following data:

- molecular mass determined by mass spectroscopy equals 6051 and conforms to theoretical value (6050.9);
- peptide map: conforms,

Isoelectric point: 6.55.

Example 13. Manufacturing of AKR insulin

Proceeding analogously to Example 10, using *Escherichia coli* strain with DNA fragment encoding AKR insulin precursor, obtained in accordance with Example 4, there has been obtained from analogous batch of inclusion bodies 4.7 g of AKR insulin of HPLC purity equal to 96.5%.

Product's structure has been confirmed by following data:

- molecular mass determined by mass spectroscopy equals 6163 and conforms to theoretical value (6163.1);
- peptide map: conforms.

Isoelectric point: 7.07.

Example 14. Manufacturing of GEKR insulin

Proceeding analogously to Example 10, using *Escherichia coli* strain with DNA fragment encoding GEKR insulin precursor, obtained in accordance with Example 5, there has been obtained from analogous batch of inclusion bodies 5.0 g of GEKR insulin of HPLC purity equal to 97.5%.

Product's structure has been confirmed by following data:

- molecular mass determined by mass spectroscopy equals 6164 and conforms to theoretical value (6164.1);
- peptide map: conforms.

Isoelectric point: 6.29.

Example 15. Manufacturing of SKR insulin

Proceeding analogously to Example 10, using *Escherichia coli* strain with DNA fragment encoding SKR insulin precursor, obtained in accordance with Example 6, there has been obtained from analogous batch of inclusion bodies 5.3 g of SKR insulin of HPLC purity equal to 98%.

Product's structure has been confirmed by following results:

- molecular mass determined by mass spectroscopy equals 6179 and conforms to theoretical value (6179.1);
- peptide map: conforms,

Isoelectric point: 7.05.

Example 16. Manufacturing of GKR insulin

Proceeding analogously to Example 10, using *Escherichia coli* strain with DNA fragment encoding GKR insulin precursor, obtained in accordance with Example 7, there has been obtained from analogous batch of inclusion bodies 6.3 g of GKR insulin of HPLC purity equal to 95.5%.

Remaining properties of the product (GKR insulin) as in Example 10.

Example 17. Manufacturing of GEKR insulin

Proceeding analogously to Example 10, using *Escherichia coli* strain with DNA fragment encoding GEKR insulin precursor, obtained in accordance with Example 8, there has been obtained from analogous batch of inclusion bodies 6.0 g of GEKR insulin of HPLC purity equal to 97%.

Remaining properties of the product (GEKR insulin) as in Example 14.

Example 18. Manufacturing of GR insulin

Proceeding analogously to Example 10, using *Escherichia coli* strain with DNA fragment encoding GR insulin precursor, obtained in accordance with Example 9, there has been obtained from analogous batch of inclusion bodies 5.5 g of GR insulin of HPLC purity equal to 96.5%.

Remaining properties of the product (GR insulin) as in Example 11.

Example 19. Manufacturing of ZKR insulin

To 1000 ml of GKR insulin solution manufactured according to Example 10 or 16 (concentration 0.1 mg/ml), in 100 mM MES/KOH buffer pH 5.0-5.5 there has been added 1μM $CuSO_4$, 100 μg/ml catalase, 5 mM ascorbic acid and 2 μM PAM enzyme (obtained according to Satani M., Takahashi K., Sakamoto H., Harada S., Kaida Y., Noguchi M.; Expression and characterization of human bifunctional peptidylglycine alpha-amidating monooxygenase. *Protein Expr Purif.* 2003 Apr; 28(2):293-302.), and subsequently mixture have been left for 2 hours at 37ºC. The reaction has been stopped by addition of 1mM Na_2EDTA.

After filtration the obtained solution has been subjected to purification with ion-exchange chromatography and HPLC methods.

Main fraction containing ZKR insulin concentrated and subjected to crystallisation using sodium citrate, zinc citrate, citric acid. From one batch of reaction mixture there has been obtained about 10 mg of crystalline ZKR insulin of HPLC purity of 97%.

Product's structure has been confirmed by following results:

- molecular mass determined by mass spectroscopy equals 6091 and conforms to theoretical value (6091.1);
- peptide map: conforms.

Isoelectric point: 7.54.

Example 20. Manufacturing of ZR insulin

To 100 ml of GR insulin solution, manufactured according to Example 11 or 18 (2 mg/ml), in 100mM MES/KOH buffer, pH 4.5, there has been added 1 μM $CuSO_4$, 100 μg/ml catalase, 5mM ascorbic acid and 2μM PAM enzyme, and subsequently the solution has been mildly mixed for 1 hour at 37ºC. The reaction has been stopped by addition of 1mM Na_2EDTA. The solution after reaction with PAM has been subjected to purification by ion-exchange and HPLC methods.

The main fraction containing insulin concentrated and subjected to crystallisation using sodium citrate, zinc citrate, citric acid. From one batch of reaction mixture there was obtained 22 mg of crystalline ZR insulin of HPLC purity of 98%.

Product's structure has been confirmed by following results:

- molecular mass determined by mass spectroscopy equals 5963 and conforms to theoretical value (5962.9);
- peptide map: conforms.

Isoelectric point: 6.97.

Example 21. Manufacturing of pharmaceutical preparation of GKR insulin (100 u/ml)

There was made 100 ml of pharmaceutical preparation of GKR insulin (100 u/ml) of following composition (values per 1.0 ml):

GKR insulin (Example 16)	3.69 mg/ml (as 100% substance, 100 u/ml)
m-cresol	2.7 mg/ml
anhydrous glycerine	16 mg/ml
zinc	30 µg/ml
water for injection	to 10 ml
pH	4.5

Preparation procedure was as follows:

There were made two following solutions:

Solution 1

Zinc oxide in amount necessary to reach the final concentration of Zn ions of 30 µg/ml were dissolved in 40 ml of 10 mM hydrochloric acid. After that, to obtained solution was added insulin GKR in amount corresponding to 10 000 u of insulin GKR, under mild stirring until obtaining a clear solution and then pH adjusted to value 4,5.

Solution 2

Separately, 270 mg of m-cresol and 1600 ml of anhydrous glycerol were dissolved in 40 ml water for injection.

Mixing of solutions 1 and 2

Solution 1 was added under stirring to Solution 2, supplemented with water for injection to volume 100 ml and in case of need corrected pH to value 4,5 with 10 mM hydrochloric acid or 0,2 M solution of sodium hydroxide. Resulting mixture was in sterile condition filtered through 0,22 µm filter and aliquoted into glass 3 ml vials. It was determined that the preparation containing GKR insulin (100 u/ml) exhibits stability in room temperature investigated period of 56 days, in the accelerated stability test (Example 24).

Example 22. Manufacturing of pharmaceutical preparation of GR insulin (100 u/ml)

There was made 100 ml of pharmaceutical preparation of GR insulin (100 u/ml) of the following composition (values per 1.0 ml):

GR insulin (Example 11)	3.61 mg/ml (as 100% substance, 100 u/ml)
m-cresol	2.7 mg/ml
anhydrous glycerine	16 mg/ml

zinc	30 µg/ml
injection water	up to 1.0 ml
pH	4.0

The procedure was identical as in Example 21, apart of that that instead of GKR insulin there was used GR insulin (in the amount of 361 mg, 10 000 u) and that the final value of pH was 4.0.

Example 23. Manufacturing of pharmaceutical preparation of GEKR insulin (100 u/ml)

There was made 100 ml of pharmaceutical preparation of GEKR insulin (100 u/ml) of the following composition (values per 1.0 ml):

GEKR insulin (Example 14)	3.70 mg/ml (as 100% substance, 100 u/ml)
m-cresol	2.7 mg/ml
anhydrous glycerine	16 mg/ml
zinc	30 µg/ml
injection water	up to 1.0 ml
pH	4.0

The procedure was identical as in Example 21, apart of that that instead of GKR insulin there was used GEKR insulin (in the amount of, 10 000 u) and that the final value of pH was 4.0.

Example 24. Examination of accelerated stability of pharmaceutical preparation of GKR insulin (100 u/ml)

Pharmaceutical preparation of GKR insulin (100u/ml), made according to Example 21, has been subjected to examination of accelerated stability (25°C ± 2°C). During this examination there were performed analysis of purity and level of protein contamination. Below there are exhibited HPLC purity of the product (GKR insulin) and the proportional contribution: highest single contamination, deamido derivative and polymers, in HPLC test, in time points of: „0", 28, 42 and 56 days.

HPLC purity test	„0"	28 days	42 days	56 days
Main peak [%]	95.10	94.33	93.98	93.60
Highest single contamination [%]	1.07	1.70	1.72	1.98
Deamido [%]	0.28	0.37	0.32	0.36
Polymers [%]	0.17	0.37	0.44	0.48

Example 25. Examination of accelerated stability of pharmaceutical preparation of GEKR insulin (100 u/ml)

Pharmaceutical preparation of GEKR insulin (100u/ml), made according to Example 23, has been subjected to examination of accelerated stability (25°C ± 2°C). During this examination there were performed analysis of purity and level of protein contamination. Below there are exhibited HPLC purity of the product (GEKR insulin) and the proportional

contribution: highest single contamination, and polymers, in HPLC test, in time points of: „0", and 14 days and 1, 2 and 3 months.

HPLC purity test	„0"	14 days	1 months	2 months	3 months
Main peak[%]	97.33	97.14	96.42	94.55	94.41
Highest single contamination [%]	0.55	0.45	0.67	1.08	1.26
Polymers[%]	not determined	0.09	not determined	0.50	not determined

Example 26. Determination of GKR activity on normoglycaemic animals

Recombined human insulin analogue (GKR insulin), similarly to Gensulin N (recombined isophane human insulin) exhibits prolonged activity time, and hypoglycaemic of normoglycaemic rats has similar course. Significant differences in hypoglycaemic activity of both preparations have been observed in 0.5 and 1 hour after administration. In this time there is observed fast and deep decrease of glucose concentration after GKR insulin. Peak activity of GKR insulin and Gensulin N is in 2^{nd} hour.

Initial research confirmed that GKR insulin is an active analogue of prolonged hypoglycaemic activity. Decrease in glucose level after GKR insulin administration was observed for up to 12 hours, while levels of glucose after 24 hours were similar to initial. Results of reaction of normoglycaemic rats to single administration of GKR insulin and Gensulin N preparations (taking into account mean values ± SEM) are shown in Table 1 and Figure 5.

Example 27. Determination of GKR insulin activity on animals with experimental diabetes

Studies on experimental model of rat diabetes (induction with streptozotocin) confirmed irrefutably hypoglycaemic activity of GKR insulin. This activity has properties of prolonged activity.

After single dose administration, the lowering of glucose concentration in blood of the examined rats remains statistically significant up to 8^{th}-10^{th} hour (depending on intensity of diabetes and dose), in comparison with control. During the research there was demonstrated faster beginning of activity and faster achieving of peak activity (beginning 30 mins, peak 1-2 hours) by GKR insulin compared to the reference preparation – insulin glargine (Lantus). Statistical significance of this phenomenon has been confirmed in severe and moderate diabetes.

Also the research of multiple dose administration of GKR insulin and the reference preparation of insulin glargine demonstrated similar activity of that both analogues. Administered for 21 days, three times per day, preparations caused improvement of glycaemy parameters in mild diabetes and, in principle, did not differ statistically in the

intensity of the effect. The only difference was noticeably more equalised activity profile of GKR insulin.

Additionally there was observed very interesting phenomenon of long-lasting hypoglycaemic effect after termination of administration of GKR preparation. This observation has been conducted on 9 rats treated with GKR preparation and 3 treated with Lantus, of the group with mild diabetes, who were administered analogues in the dose of 5 u/kg bm for 21 days. Obtained results can be an evidence of existence of very strong bounding of GKR insulin in tissues (possibly subcutaneous tissue). They support thesis of existence of compartment, in which insulin is accumulated and slowly redistributed. This phenomenon was not observed for the reference preparation. This property, after its confirmation in humans, could be a breakthrough in therapy with prolonged activity insulin analogues, allowing e.g. administration of less than one dose of the medicine per day.

The results describing glucose concentration in rat blood after single dose administration of GKR insulin in the dose of 5 u/kg bm in the mild streptozotocin-induced diabetes model (in comparison with Lantus preparation) are shown in Table 2 and Fig. 6.

The results describing influence of GKR insulin on glucose concentration in rat blood after single dose one-time administration of doses 2.5 u/kg bm, 5 u/kg bm and 7.5 u/kg bm in severe streptozotocin-induced diabetes model (in comparison with Lantus preparation and control) are shown in Table 3.

The results presenting influence of GKR insulin on glucose concentration in rat blood after single dose administration of doses 2.5 u/kg bm, 5 u/kg bm and 7.5 u/kg bm in severe streptozotocin-induced diabetes model (in comparison with control) are shown in Fig 7.

The results presenting influence of GKR insulin on glucose concentration in rat blood after single dose administration of 7.5 u/kg bm in severe streptozotocin-induced diabetes model (in comparison with Lantus preparation) are shown in Fig 8.

The results describing glucose concentration in rat blood after multiple dose administrations of 5 u/kg bm of GKR insulin in mild streptozotocin-induced diabetes model (in comparison with Lantus preparation) are shown in Table 4 and Fig 9.

The results describing glucose concentration in rat blood after termination of administrations of 5 u/kg bm of GKR insulin in mild streptozotocin-induced diabetes model (in comparison with Lantus preparation) are shown in Table 5 and Fig 10.

l	Volume s.c. ,3ml/ 300 g bm	91.5±2.0	87.0±2.1	88.7±1.7	88.9±2.0	87.4±3.2	88.7±2.2	93.0±2.0	91.3±2.2	93.0±2.

al groups n=10; * EM; **WO 2010/002283** **PCT/PL2009/050010**
gnificance **p<0,01 GKR insulin vs. initial glucose concentration; ##p<0,01, #p<0,05 Gensulin N vs. initial glucose concentration; ^^p<(
g bm vs. Gensulin N 2 u /kg bm.
eath of one animal in the 2nd hour.

ıfluence of single dose administration of GKR insulin in a dose of 5 u/kg bm on glucose concentration in blood of rats with mild streptoz
duced diabetes, compared with Lantus preparation (insulin glargine).

model	Tested preparation	dose s.c.	number of rats in the group	concentration of glucose in rat blood mean value (mg/dl) ± SEM								
				normo-glycaemy	fixed hyperglycaemy	time of blood sampling after single dose administration of the p (hours)						
					0	0,5	1	2	4	6	8	10	12
l tocyn- 2 mg/kg m.)	GKR	5 u/kg bm	20	82.5 ± 3.0	250.7 ± 22.2	115.6 ± 16.1 ^^	84.1 ± 7.8 ^^	93.3 ± 4.8 ^^	106.7 ± 7.2 ^^	117.0± 4.9**^^	130.3 ± 6.9 ^^	142.0 ± 7.9 ^^	173.4 ± 18.6
	Lantus		9	103.6±2.9	229.2 ± 32.5	135.6 ± 27.1	72.6 ± 5.2	69.7 ± 8.4	77.9 ± 6.8	76.8 ± 5.7	106.1 ± 6.0	128.2 ± 13.1	199.8 ± 36.6
	control	10 nl/200g bm	9	91.3 ± 5.9	236.1 ± 7.7	222.2 ± 24.8	205.3 ± 21.5	207.4 ± 21.8	203.4 ± 20.4	205.9 ± 21.3	212.0 ± 24.1	213.6 ± 23.1	213.2 ± 25.6

gnificance: ** p < 0,01 * p < 0,05 GKR vs. Lantus
^^ p<0,01 ^ p < 0,05 GKR vs. control

	tion		group	caemy	mia	(hours)								
					0	0,5	1	2	4	6	8	10	12	2
	GKR	2,5 u/kg bm	10	86.3 ± 3.4	570.8 ± 20.1	251.4 ± 41.2 ** ^^	170.2 ± 28.8 ** ^^	250.0 ± 37.8 ** ^^	377.4 ± 35.0 ** ^^			524.2 ± 45.3	560.1 ± 33.0	55 ± 4
	Lantus		10	84.4 ± 3.8	596.8 ± 3.1	376.5 ± 24.3	284.3 ± 28.7	134.55 ± 22.9	209.1 34.4	314.6 ± 52.4	415.2 ± 40.0	502.6 ± 25.5	546.4 ± 17.5	53 ± 2
cin-	GKR	5 u/kg bm	11	84.7 ± 4.0	585.9 ± 7.5	235.3 ± 32.0 ^^	122.6 ± 21.1 ^^	119.6 ± 11.6 ^^	245.2 ± 26.7 ** ^^	367.4 ± 29.9 ** ^^	421.1 ± 33.8 ** ^	483.5 ± 30.6	546.7 ± 40.1	59 ±
–	Lantus		11	81.6 ± 3.2	572.9 ± 12.6	302.3 ± 42.7	173.4 ± 33.7	123.1 ± 21.4	131.3 ± 10.9	152.5 ± 14.6	262.2 ± 36.7	426.7 ± 39.8	502.6 ± 26.5	58 ±
)m,	GKR	7.5 u/kg bm	10	89.0 ± 3.4	573.9 ± 18.8	259.1 ± 14.2 * ^^	133.1 ± 19.3 ^^	109.2 ± 11.8 ^^	216.1 ± 32.6 ** ^^	280.6 ± 42.3 ^^	350.6 ± 49.2 ^^	508.7 ± 34.0 *	526.4 ± 27.3	57 ± 2
	Lantus		10	82.4 ± 3.5	594.0 ± 6.0	335.4 ± 28.5	198.3 ± 36.7	106.1 ± 22.4	105.5 ± 16.8	188.7 ± 28.7	309.5 ± 54.1	402.6 ± 49.3	461.6 ± 38.4	59 ± 3
	control	10 µl/200 g bm	9	74 ± 3.6	592.1 ± 5.4	578.6 ± 10.2	594.2 ± 5.4	579.2 ± 13.0	548.8 ± 23.5	526.0 ± 25.5	547.3 ± 23.7	544.9 ± 14.0	575.3 ± 12.4	59 ±

WO 2010/002283 PCT/PL2009/050010

gnificance: ** p < 0,01 * p < 0,05 GKR vs. Lantus
^^ p < 0,01 ^ p < 0,05 GKR vs. control

	9	103.6 ± 2.9	228.9 ± 30.7	136.3 ± 8.1	147.0 ± 9.0	173.7 ± 10.4	184.9 ± 12.7	163.7 ± 11.2	171.4 ± 10.4	175.8 ± 8.8	168.4 ± 15.7
om	5	88.8 ±	243.4 ± 4.7	229.4 ± 13.3	232.6 ± 10.6	227.0 ± 9.9	254.4 ± 9.1	257.0 ± 8.4	247.0 ±	258.0 ± 6.7	257.0 ± 7.9

tio	number of rats in the group	glucose concentration in blood of the rats, mean value (mg/dl) ± SEM									
		normoglycaemia	fixed hyperglycaemia	consecutive days of study							
				11	12	13	14	15	16	17	18	19
	20	82.5 ± 3.0	198.1 ± 12.1	152.6 ± 2.3 ^^	153.6 ± 2.9 ^^	149.7 ± 3.1 ^^	151.5 ± 3.3 ^^	151.1 ± 3.4 ^^	149.0 ± 5.6 ^^	142.7 ± 3.2 ** ^^	143.0 ± 4.9 ^^	149.7 ± 4.7 ^
	9	103.6 ± 2.9	228.9 ± 30.7	164.8 ± 13.9	170.6 ± 19.3	161.6 ± 15.6	144.0 ± 18.3	124.9 ± 14.7	156.7 ± 7.5	191.3 ± 19.1	141.0 ± 11.4	172.1 ± 33.1
om	5	88.8 ± 9.4	243.4 ± 4.7	248.4 ± 8.4	255.0 ± 5.5	260.0 ± 11.7	252.0 ± 14.9	249.6 ± 20.4	256.2 ± 8.8	255.0 ± 19.4	259.4 ± 16.7	233.6 ± 11.4

gnificance: ** $p < 0,01$ * $p < 0,05$ GKR vs. Lantus
^^ $p < 0,01$ ^ $p < 0,05$ GKR vs. control

ucose concentration in the period after termination of administration of GKR insulin in the dose of 5 u/kg bm in the model of mild strept
luced, in comparison with Lantus preparation (insulin glargine).

sted ration	glucose concentration in rat blood, mean value (mg/dl)							
	normoglycaemia	fixed hyperglycaemia	in the last day of administration	days after termination of administration of tested preparati				
				1	2	3	5	8
g bm	86.1 ± 3.7	214.4 ± 24.3	148.3 ± 8.5	146.4 ± 9.4	136.0 ± 7.8	137.4 ± 6.6	132.8 ± 3.1	123.2 :
/kg bm	103.3 ± 1.2	254.0 ± 67.8	141.0 ± 18.2	282.3 ± 58.2	277.7 ± 72.6	235.0 ± 89.7	158.7 ± 40.3	195.3 ±

Example 28. Determination of GR insulin activity in animals with experimental diabetes

Hypoglycaemic activity of GR insulin has been confirmed in a moderate streptozotocin-induced diabetes in rats.

Activity of GR insulin after administration of single doses – 5 u or 10 u/kg bm has been determined to be fast and strong. Beginning of activity occurs already after 30 minutes after administration of the preparation and remains at the same level up to 2 hours, and subsequently weakens until reaching initial levels in 24^{th}-36^{th} hour.

Results describing influence of GR insulin preparation on glucose concentration in blood of rats after single dose administration of 5 u and 10 u/kg bm doses in a model of moderate streptozotocin-induced diabetes (in comparison with Lantus preparation) are shown in Table 6. A plot of glucose concentration/time changes after administration of 5 u/kg bm of GR insulin is shown in Fig.11.

Example 29. Determination of GEKR insulin activity in animals with experimental diabetes

Hypoglycaemic activity of GEKR insulin analogue has been confirmed in a preliminary study on a rat streptozotocin-induced diabetes of moderate course.

After single administration of GEKR insulin in a dose of 10u/kg bm there was observed very quick (already after 0.5 hour), strong activity reducing glucose concentration in animals' blood. This activity peaked already one hour after administration of the preparation and slowly decreases, still causing significant decrease of glucose level in comparison to initial values up to 12 hours after administration. This research was conducted in comparison with Levemir preparation, insulin analogue of prolonged activity (insulin detemir).

Results describing influence of GEKR insulin on glucose concentration in rat blood after single dose administration of 10 u/kg bm in a moderate streptozotocin-induced model of diabetes, in comparison with preparation Levemir, are shown in Table 7, and a plot of glucose concentration change as a function of time after administration 10 u/kg bm of GEKR insulin in Fig 12.

	GR	5.0 u/kg bm	15	80.6 ± 2.4	507.4 ± 22.9	113.9± 10.8**	98.5± 7.6	92.5± 6.7	160.3± 18.3	198.1±2 2.6*	268.7± 29.3	294.9± 29.4	353.0± 28.5	40(28
	Lantus		5	83.0 ± 4.3	600.0 ± 0.0	324.8 ± 35.3	136.6 ± 27.0	102.2 ± 20.4	97.2 ± 11.2	94.8	157.6	266.6 60.5	401.4 ± 60.4	6(±
	GR	10 u/kg bm	15	84.9 ± 3.7	498.7 ± 25.4	96.1 ± 8.1**	85.7 ± 4.4**	77.0 ± 3.5	151.5 ± 14.9	21.0	26.2*	248.9 ± 30.6	326.1 ± 27.9	38(2
	Lantus		6	77.8 ± 2.3	550.2 ± 33.9	247.8 ± 25.6	134.0 ± 21.8	75.0 ± 8.1	109.3 ± 16.0	94.7 ± 20.0	103.7 ± 20.9	148.8 ± 20.4	223.3 ± 42.2	38(1
	control	10 µl/200 g bm	6	80.5 ± 2.9	509.5 ± 40.6	527.2 ± 32.5	532.0 ± 30.9	495.5 ± 26.8	463.5 ± 26.9	497.2 ± 23.6	452.8 ± 31.8	491.7 ± 27.8	520.3 ± 31.2	5(±

WO 2010/002283 PCT/PL2009/050010

gnificance: ** p < 0,01 * p < 0,05 GR vs. Lantus

luence of single dose administration of GEKR insulin (in a dose of 10 u/kg bm) on glucose concentration in blood of rats with moderate
n comparison with Levemir preparation (insulin detemir).

del	Tested preparation and dose s.c.	Concentration of glucose in rat blood mean value (mg/dl) ± SEM							
		normoglycaemia	fixed hyperglycaemia	Time of blood sampling after single dose administration (hours)					
				0.5	1	4	6	8	
in-	GEKR 10 u/kg bm	90.5 ± 6.4	469.5 ± 65.8	218.0 ±19.7	109.3±10.1	143.7 ± 22.4	-	242.3 ±59.2	32
n, i.m.)	Levemir 10 u/kg bm	98.5 ± 3.5	502.5 ± 26.2	-	-	-	142.3 ± 22.3	-	38

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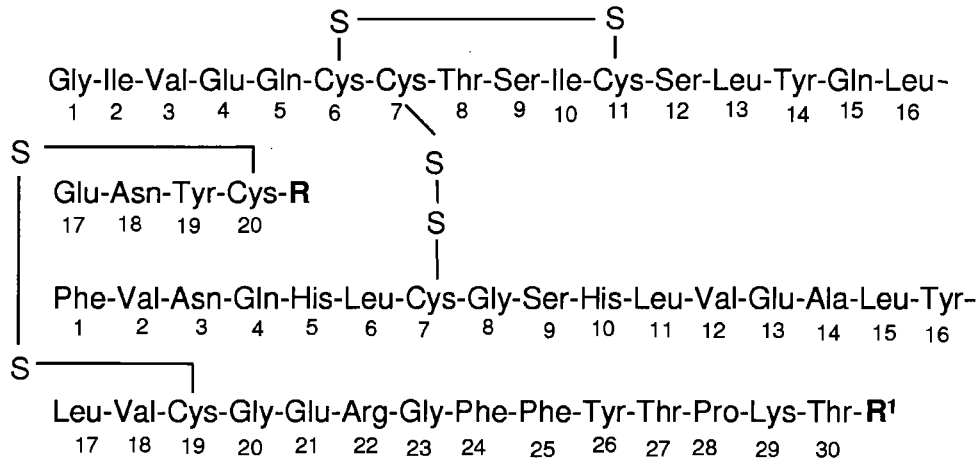
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Claims

1 Insulin derivative or its pharmaceutically acceptable salt containing two polypeptides forming chain A and chain B, where amino acid sequence of chain A has been chosen from SEQ ID No 1 – 6, while amino acid sequence of chain B has been chosen from SEQ ID No 7 – 10.

2 Insulin derivative or its pharmaceutically acceptable salt according to claim 1, characterised by being an analogue of recombined human insulin of isoelectric point 5-8.5 and being of formula 1:



where R denotes group NH_2 or group of formula Asn-R^2, where R^2 denotes neutral L-amino acid or group NH_2;

and R^1 denotes B31Lys-B32Arg or B31Arg-B32Arg or B31Arg, where B3Asn can be optionally replaced by another amino acid, favourably by Glu.

3 Insulin derivative or its physiologically acceptable salt according to claim 2, characterised in that:

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Gly and R^1 denotes B31Lys-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Ala and R^1 denotes B31Lys-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Ser and R^1 denotes B31Lys-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Thr and R^1 denotes B31Lys-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes group NH_2 and R^1 denotes B31Lys-B32Arg, or

R in formula 1 denotes group NH_2 and R^1 denotes B31Lys-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Gly, and R^1 denotes B31Arg-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Ala and R^1 denotes B31Arg-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Thr and R^1 denotes B31Arg-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Ser and R^1 denotes B31Arg-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes group NH_2 and R^1 denotes B31Arg-B32Arg, or

R in formula 1 denotes group NH_2 and R^1 denotes B31Arg-B32Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Gly, and R^1 denotes B31Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Ala, and R^1 denotes B31Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Thr, and R^1 denotes B31Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes Ser, and R^1 denotes B31Arg, or

R in formula 1 denotes group of formula Asn-R^2, where R^2 denotes group NH_2, and R^1 denotes B31Arg, or

R in formula 1 denotes group NH_2 and R^1 denotes B31Arg, or

R in formula 1 denotes group of formula Asn-R^2 where R^2 denotes Gly, R^1 denotes B31Lys-B32Arg, and B3Asn has been replaced with B3Glu.

4. Pharmaceutical composition, characterised in, that it contains effectively acting amount of insulin derivative or its pharmaceutically acceptable salt according to one of claims from 1 to 3.
5. Pharmaceutical composition according to claim 4, characterised in, that it contains 10 up to 50 µg/ml of zinc.
6. Use of insulin derivative or its pharmaceutically acceptable salt according to one of claims from 1 to 3 to manufacture a medicine for treatment or prevention of diabetes mellitus.
7. Method of treatment of patients suffering from diabetes mellitus, characterised in, that to patient requiring such a treatment is administered an effectively acting amount of pharmaceutical composition according to claims 4 and 5.