Cyclic angiotensin analogs

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(57) Abstract: The invention relates to analogs of angiotensins, in particular to cyclised analogs having Ang(1-8) agonistic or antag-
onistic activity and to cyclised Ang(1-7) analogs with agonistic or antagonistic activity and displaying improved proteolytic resistance
compared to their linear counterparts. Provided is a cyclic angiotensin peptide analog comprising a thioether-bridge linkage between
the amino acids corresponding to positions Tyr^4 and Pro^7 in naturally occurring Angiotensin. Also provided is the use of analogs in
therapy, for example hypertension.

Cyclic angiotensin analogs

The invention relates to analogs of angiotensins, in particular to
cyclised analogs having Ang(1-8) receptor agonistic and/or antagonistic
activity, or Ang(1-7) receptor agonistic or antagonistic activity, and displaying
improved proteolytic resistance compared to their linear counterparts. In
5   particular, it relates to cyclised analogs having Ang(1-8) receptor antagonistic
activity and Ang(1-7) receptor agonistic. Also provided is the therapeutic use of
the cyclised peptide analogs.
        The octapeptide angiotensin-II (Asp-Arg-Val-Tyr-Ile-His-Pro-Phe),
also referred to as AngII or Ang(1-8) is one of the oldest peptide hormones,
10   known for its multiplicity of biological actions related to endocrine or
connected to the central and peripheral nervous system.
        Ang(1-8) has multiple physiologic effects that regulate vascular
tone, hormone secretion, tissue growth and neural activity. It has systemic and
local effects, favoring cell growth and differentiation through four types of
15   receptors. It may be applied in tissue repair and development. Antagonists of
Ang(1-8) can be applied in antitumor action by inhibition of angiogenesis
(Escobar et al 2004 Current Vascular Pharmacology 2, 385-399). Receptors of
the renin angiotensin system (RAS) may be involved in the differentiation of
stem cells (Ozturk et al 2004 Medical hypotheses 63, 866-874). Ang(1-8)
20   receptor blockers are widely used for heart and renal failure and hypertension.
        Ang(1-8) is a potent pressor agent, which has a vital role in the
regulation of blood pressure, in the conservation of total blood volume and salt
homeostasis. Furthermore, it is involved in the release of alcohol
dehydrogenase (ADH), cell growth and the stimulation of the sympathetic
25   system. Several antagonists of Ang(1-8) are efficient antipressor agents.
Inadequate functioning of the renin–angiotensin system contributes
substantially to the development of hypertension and cardiovascular and renal

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pathology (including left ventricular hypertrophy, structural alternations of the vasculature, neointima formation, nephrosclerosis, etc.).

Structure–activity relationships studies from several laboratories have revealed the topological contribution of the individual amino acid

5   residues of the active Ang(1-8) molecule (Regoli et al., (1974) Pharmacol. Rev. 26, 69–123; Kholsa et al., (1974) Structure–activity relationship in angiotensin II analogs. In Handbook Exp. Pharmacol. – Angiotensin (Page, I.H. & Bumpus, F.M., eds), pp. 126–161. Springer-Verlag, Berlin; Cordopatis et al.(1999) In Bioactive Peptides in Drug Discovery and Design. Medical Aspects

10   (Matsoukas, J. & Mavromoustakos, T., eds), pp. 25–32. IOS Press, Amsterdam, NL). These studies have included theoretical, physicochemical, and spectroscopic investigation and have led to several models for the Ang(1-8) structure in solution.

Ang(1-8) is produced by the conversion of its precursor decapeptide

15   angiotensin-I (Asp–Arg–Val–Tyr–Ile–His–Pro–Phe–His–Leu; herein also referred to as AngI or Ang(1-10)) to Ang(1-8) by the action of the angiotensin-I converting enzyme (ACE) of the vascular endothelium. Upon ACE hydrolysis, the inactive Ang(1-10) is converted to the biologically active Ang(1-8). The two peptides differ in the length and nature of their C-terminus; Ang(1-8) lacks the

20   His-Leu terminal dipeptide. Ang(1-10) is generated in the circulation by the action of renin from the kidneys on its substrate, called alpha2-globulin or angiotensinogen, produced in the liver (Do et al., J. Biol. Chem. 262, 1037–1043).

ACE is a target for inactivation by ACE inhibitor drugs, which

25   decrease the rate of angiotensin II production. The renin-angiotensin system plays a critical role in blood pressure control and body fluid and electrolyte homeostasis. Besides Ang(1-8), several other cleavage products of Ang(1-10) have been identified, for example, Ang(1-9), Ang(1-7), Ang III (Ang(2-8)), and Ang IV (Ang(3-8)).

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Angiotensin-(1-7) (Ang(1-7)), a heptapeptide biologically active member of the renin-angiotensin peptide family, antagonizes the RAS system at various levels. Being a substrate for ACE, Ang(1-7) competes with Ang I and bradykinin for degradation, thereby inhibiting Ang II formation and

5   augmenting bradykinin activity. Ang(1-7) has also been found to block the deleterious actions of Ang II through a noncompetitive blockade of AT1 receptors and direct stimulation of angiotensin type 2 (AT2) receptors. Although ACE inhibitors were originally developed to suppress the formation of Ang II, part of their beneficial effect in cardiovascular diseases may be

10   attributed to the resultant elevation in Ang(1-7) levels. ACE inhibitor treatment, although having limited effects on the circulating amount of Ang II, increases Ang(1-7) levels 10- to 25-fold.

Intravenous infusion of Ang(1-7) inhibited smooth muscle cell proliferation associated with balloon-catheter injury (Strawn W.B. et al.

15   Angiotensin(1-7) reduces smooth muscle growth after vascular injury, Hypertension 33:207-11 , 1999). Ang(1-7) also opposes the mitogenic response to Ang Il in cultured VSMCs. Further, Ang(1-7), through interaction with its recently discovered Ang(1-7) receptor, has a vasodilatory effect by way of stimulating nitric oxide release.

20   Ang(1-7) has become an angiotensin of particular interest in the past few years, because its cardiovascular and baroreflex actions counteract those of Ang(1-8). Unique angiotensin-binding sites specific for this heptapeptide and studies with a selective Ang(1-7) antagonist indicated the existence of a distinct Ang(1-7) receptor. Santos RA, et al. (Proc Natl Acad Sci U S A. 2003

25   Jun 26) demonstrated that genetic deletion of the G protein-coupled receptor encoded by the Mas protooncogene abolishes the binding of Ang(1-7) to mouse kidneys. Accordingly, Mas-deficient mice completely lack the antidiuretic action of Ang(1-7) after an acute water load. Ang(1-7) binds to Mas-transfected cells and elicits arachidonic acid release. Furthermore, Mas-deficient aortas

30   lose their Ang(1-7)-induced relaxation response. Collectively, these findings

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identify Mas as a functional receptor for Ang(1-7) and provide a clear
molecular basis for the physiological actions of this biologically active peptide.

Both Ang(1-8) and Ang(1-7) have been shown to facilitate tissue
repair like in skin wound healing (Yahata et al (2006) J Biol. Chem 281,

5   13209-13216) and after artery stent placement (Langeveld et al (2005)
Hypertension 45, 138-141). Also, beneficial effect on bone marrow suppression
during chemotherapy has been shown. In contrast to Ang(1-8), Ang(1-7) does
not possess the adverse hypertensive properties. This makes especially Ang(1-
7), and analogs thereof, of interest for these applications.

10   Ang(1-7) and Ang(1-8) have been reported to play a role in
multiple other therapeutic effects. Ang(1-7) may have a beneficial role before
and after chemotherapy in patients with newly diagnosed breast cancer
(Rodgers et al 2006 Cancer Chemother Pharmacol 57, 559-568) and it inhibits
lung cancer, *in vitro*, (Gallagher & Tallant. 2004. Carcinogenesis 25, 2045-

15   2052). Ang(1-7) inhibits growth of human adenocarcinoma xenografts in nude
mice through a reduction in cyclooxygenase-2 (Menon, Soto-Pantaja, Callahan,
Clin, Ferrario, Tallant & Gallagher 2007 Cancer Res. 67:2809-15.)
Angiotensin(1-7) prevents diabetes-induced cardiovascular dysfunction
(Benter, Yousif, Cojocel, Al-Maghrebi, Diz 2007 Am J Heart Circ Physiol 292,

20   H666-72.)

Ang(1-8) is degraded in the body to angiotensin III (Arg-Val-Tyr-Ile-
His-Pro-Phe; or Ang(2-8) by angiotensinases that are located in red blood cells
and the vascular beds of most tissues. It has a half-life in humans of 1-2
minutes. Angiotensin III has 40% of the pressor activity of Angiotensin II, but

25   100% of the aldosterone-producing activity.

Angiotensin IV (Val-Tyr-Ile-His-Pro-Phe; or Ang(3-8) is a
hexapeptide which, like angiotensin III, has some lesser activity.

Angiotensins II, III & IV have a number of effects throughout the
body. For example, they have, cardiovascular effects because they are potent

30   and direct vasoconstrictors, constricting arteries and veins and increasing

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blood pressure. Angiotensin II has prothrombotic potential through adhesion and aggregation of platelets and production of PAI-1 and PAI-2. It has been thought that angiotensin II could be a cause of vascular and cardiac muscle hypertrophy.

5   Furthermore, Ang(1-8) increases thirst sensation through the subfornical organ (SFO) of the brain, decreases the response of the baroreceptor reflex, and increases the desire for salt. It increases the secretion of ADH in the posterior pituitary and ACTH in the anterior pituitary. It also potentiates the release of norepinephrine by direct action on postganglionic 10   sympathetic fibers.

         Ang(1-8) acts also on the adrenal cortex, causing it to release aldosterone, a hormone that causes the kidneys to retain sodium and lose potassium. Elevated plasma angiotensin II levels are responsible for elevated aldosterone levels during the luteal phase of the menstrual cycle.

15   Ang(1-8) also has trophic effects on the vasculature, promoting growth of the muscles in the arterial wall. It is also thought to be angiogenic, i.e. it causes vascularisation of newly developing tissue.

         In addition, Ang(1-8) has a direct effect on the proximal tubules to increase Na^+ resorption. Although it slightly inhibits glomerular filtration by 20   indirectly (through sympathetic effects) and directly stimulating mesangial cell constriction, its overall effect is to increase the glomerular filtration rate by increasing the renal perfusion pressure via efferent renal constriction.

         Clearly, the family of angiotensin hormone peptides is involved in mediating important physiological effects. Accordingly, the development of 25   angiotensin analogs, having either agonist or antagonist activity, that are of use as therapeutic agents has received a lot of attention. However, the medical and industrial application of small, linear peptides is severely restricted by their limited stability. It is well known in the art of peptide drug design that cyclization of a linear peptides can induce structural rigidity, thereby 30   preventing degradation. Furthermore, if designed carefully without causing

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drastic changes in the conformation of active peptides, the rigid geometry of
the cyclic peptides may enhance the binding affinity towards a selected target
molecule compared to their linear counterparts. Also, cyclic analogs can serve
as important intermediates in the design and synthesis of non-peptide
5   mimetics with the potential to be used as drugs.

During the last decades, numerous cyclization methods have been
applied for the preparation of mono- and bicyclic peptides. In many cases, the
objective was to probe the bioactive conformation(s) of a target peptide by
reducing the conformational stability or to produce more metabolically stable
10   compounds. Disulfide and amide cyclizations are among the most commonly
used monocyclization methods (Hruby et al., Biochem J. 1990 Jun
1;268(2):249-62), but other strategies have also been employed including, for
example, thioether-cyclizations (Feng et al., Organic Lett. 1999, 1, 121; Jones
et al., Tetrahedron Lett. 1998, 39, 6107; WO93/03056).

15   A number of different conformationally restricted cyclized Ang(1-8)
analogs have been described in the art. Cyclization was achieved among others
by the disulfide method using cysteine moieties at various positions of the
peptide molecule or by the amide-linkage method. See for example Miura et
al., J Biol Chem. 1999 Mar 12;274(11):7103-10; Miranda et al., Braz J Med
20   Biol Res. 1988;21(5):903-14; Spear et al., J Med Chem. 1990 Jul;33(7):1935-40;
Nikiforovich et al., Biochemistry. 1994 Mar 29;33(12):3591-8; Zhang et al., J
Med Chem. 1996 Jul 5;39(14):2738-44). Poleyava et al. (Bioorg Med Chem.
2001 Jun;9(6):1639-47) disclosed a constrained cyclic AngII analog with a
lactam amide bridge linking a Lys-Glu pair at positions 3 and 5 of the peptide
25   and possessing Ile at position 8. This analog was found to be an inhibitor of
AngII. Lindmann et al., (Bioorg Med Chem. 2001 Mar;9(3):763-72) described
cyclic 12-, 13- and 14-atom membered ring AngII analogs encompassing
methylene-dithioether bridges.

Other structure-activity studies have illustrated the importance of
30   the C-terminal residue Phe for agonistic activity of Ang(1-8). Replacement of

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Phe[8] with an aliphatic one, e.g. Ile, results in an antagonist [Sar1-Ile8] AngII, also known as Sarilesin (Mavromoustakos et al., J. Med. Chem., 1999, 42, 1714; Ganter et al., J. Med. Chem. 1995, 38, 4660). Mutation studies have also shown that the aromaticity of Phe[8] position is important for receptor activation

5   (Roumelioti et al., Bioorg. Med. Chem. Lett. 2000, 10, 1).

The above illustrates that there is a great interest in the development of novel angiotensin analogs. The present inventors set out to design and synthesize further angiotensin analogs which display biological activity and which are metabolically stable. In particular, they aimed to

10   provide Ang(1-8) and Ang(1-7) analogs which display enhanced resistance to proteolytic degradation as compared to their linear counterparts while retaining a biological activity, said biological activity being either of the same type or of a different type. A further aim was to converting an Ang agonist into an Ang antagonist, or vice versa.

15   These goals are met by the surprising finding that the introduction of a thioether-ring structure between the amino acids corresponding to positions 4 and 7 in naturally occurring angiotensins (e.g. Ang(1-8) or Ang(1-10), Tyr[4] and Pro[7], results in a biologically active angiotensin-analog having an enhanced resistance against proteases.

20   The increased proteolytic resistance of the therapeutic Ang-analog, or a precursor thereof, allows for a much higher therapeutic potential, lower dose and/or a lower frequency of administration, and may allow effective oral administration. Furthermore, an overall increase in stability may allow for an increased shelf-life of the peptide analog.

25   Accordingly, the invention provides a cyclic angiotensin peptide analog comprising a thioether-bridge linkage between the amino acids corresponding to positions Tyr[4] and Pro[7] in linear, naturally occurring angiotensin, like in human AngI (Ang(1-10).

Biologically active angiotensin analogs wherein the amino acids at

30   positions 4 and 7 (all positions referred to herein correspond to the numbering

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as in naturally occurring Ang, unless indicated otherwise) are modified to a cyclic structure have not been previously disclosed. In fact, it is highly surprising that modification of Tyr[4] does not abolish the biological activity of an angiotensin for the following reasons. Accumulated experimental evidence

5   for AngII supports a bioactive conformation characterized by a charge relay system between Tyr hydroxyl, His imidazole and Phe carboxylate, analogous to that found in serine proteases, as well as a ring cluster of the triad key amino acids Tyr[4]-His[6]-Phe[8] which is suggested to be responsible for activity. The ring cluster conformation was supported by the design and synthesis of a novel

10   constrained AngII cyclic analog, [Sar1-Lys3-Glu5] AngII (Matsoukas *et al.* Bioorg. Med. Chem. 2000, 8, 1).
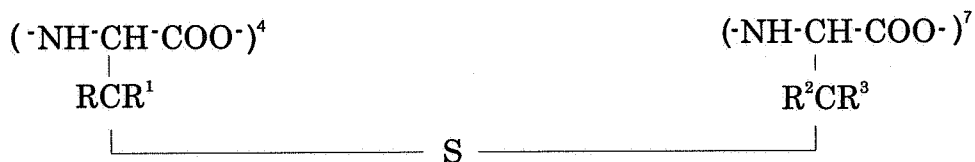
       Furthermore, interactions between Tyr[4] and Phe[8] of Ang(1-8) with Asn[111] and His[256], respectively, of the AngII type I (AT1) receptor were reported to be essential for agonistic activity (Noda *et al.*, (1996) Biochemistry,

15   35, 16435). Miura *et al.* (1999, J. Biol. Chem., Vol. 274, No.11, pp.7103) subsequently reported that it is primarily the aromaticity, and secondarily the size of the Tyr[4] side chain that is important in activating the receptor. Beta-cyclohexylalanine replacements at either position 4 or 8 hindered ligand-dependent activation of the receptor.

20   In view of the above evidence for Tyr[4] being critical for angiotensin function, the present finding that a thioether-ring structure can be introduced at positions 4 and 7 without compromising biological activity is clearly unexpected. The expression "without compromising biological activity" is meant to indicate that the cyclised analog has at least some activity in vitro

25   and/or in vivo. In qualitative terms, the nature of the activity can be identical to that of the linear counterpart, e.g. a linear Ang(1-7) peptide having agonistic activity is cyclised to yield a more stable agonist, or the activity can be different, e.g. a linear agonist becoming an antagonist when cyclised through the residues at positions 4 and 7. In quantitative terms, it is noted that for a

30   cyclic analog the activity need not be as high as the linear counterpart; a loss

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of 90% of activity upon ring introduction can still yield a peptide of great interest if its stability is 1000 times higher than its linear counterpart.

A thioether bridge is also referred to as a monosulfide bridge or, in the case of Ala-S-Ala, as a lanthionine bridge. Thioether-bridge containing peptides can be formed by two amino acids having either one of the following general formulas:

Formula A
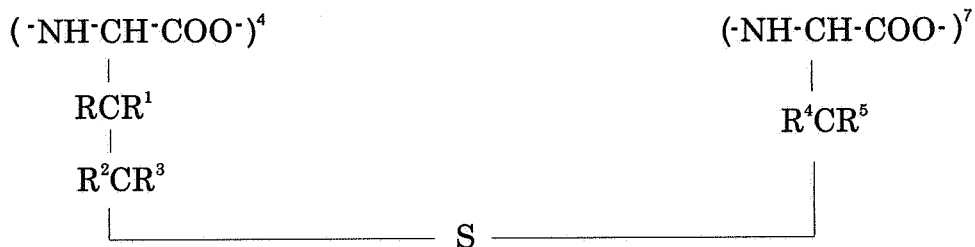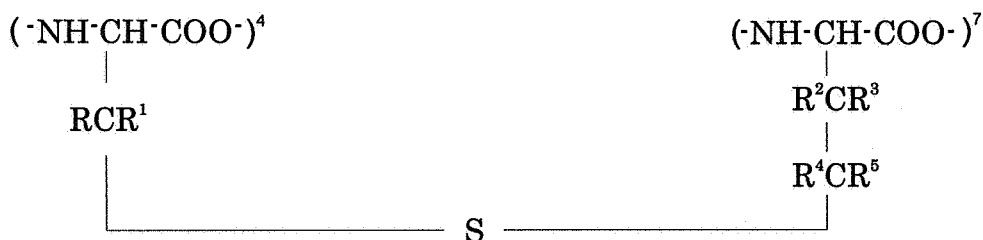
$$(^-NH^-CH^-COO^-)^4 \qquad\qquad (^-NH^-CH^-COO^-)^7$$
$$\underset{|}{RCR^1} \qquad\qquad \underset{|}{R^2CR^3}$$
$$\underline{\qquad\qquad\qquad} S \underline{\qquad\qquad\qquad}$$

Formula B:

$$(^-NH^-CH^-COO^-)^4 \qquad\qquad (^-NH^-CH^-COO^-)^7$$
$$\underset{|}{RCR^1} \qquad\qquad\qquad \underset{|}{R^4CR^5}$$
$$\underset{}{R^2CR^3}$$
$$\underline{\qquad\qquad\qquad} S \underline{\qquad\qquad\qquad}$$

Formula C:

10

$(^-NH^-CH^-COO^-)^4$ $(^-NH^-CH^-COO^-)^7$
            | |
        RCR^1 R^2CR^3
            | |
            | R^4CR^5
            |_____ S _____|

wherein R^1, R^2, R^3 , R^4 and R^5 are independently selected from –H, a lower (e.g.

5   C_1-C_{10}) alkyl or aralkyl group. In a preferred embodiment, R^1, R^2, R^3 , R^4 and

R^5 are independently selected from H and CH_3.

In one embodiment, the invention provides a peptide comprising a thio-ether

bridge according to formula A, i.e. wherein the linkage between the amino

10   acids at positions 4 and 7 has the meaning –RCR^1-S-R^2CR^3 -, wherein R, R^1, R^2

and R^3 are independently selected from –H, a lower (e.g. C_1-C_{10}) alkyl or

aralkyl group. R, R^1, R^2 and R^3 are preferably independently selected from H

and CH_3. Peptides comprising a thio-ether bridge according to formula A can be

made for example by lantibiotic enzymes or by sulfur extrusion from a

15   disulfide. The disulfide from which the sulfur is extruded can be formed by a

D-cysteine in position 4 and a L-cysteine in position 7 or by one D-cysteine in

position 4 and a L-penicillamine in position 7 [Galande, Trent and Spatola

2003 Biopolymers 71, 534-551].

20   Alternatively, the linkage of the two amino acids can be composed of RCR^1-

R^2CR^3-S-R^4CR^5 (Formula B) or RCR^1-S-R^4CR^5-R^2CR^3 (Formula C), in which R,

R^1, R^2, R^3, R^4 and R^5 independently represent –H, a lower (e.g. C_1-C_{10}) alkyl or

aralkyl group. Peptides comprising a thio-ether bridge according to formula B

can for instance be made by sulfur extrusion of a disulfide formed by a D-

25   homocysteine in position 4 and a L-cysteine in position 7 [Galande, Trent and

Spatola 2003 Biopolymers 71, 534-551]. Likewise, peptides comprising a thio-

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ether bridge according to formula C can for instance be made by sulfur extrusion of a disulfide formed by a D-cysteine in position 4 and a L-homocysteine in position 7 [Galande, Trent and Spatola 2003 Biopolymers 71, 534-551].

It is convenient that a peptide analog of the invention can be made in a biological system, in particular making use of the lantibiotic enzyme system of a (bacterial) host cell. Accordingly, peptides comprising a thioether-bridge according to formula A are preferred.

The term "cyclic angiotensin peptide analog" refers to any angiotensin analog having biological activity and / or being capable of selective receptor binding, or an inactive precursor thereof which can be proteolytically activated, e.g. in a fashion that is similar to Ang(1-10) conversion to active fragments. The analog will typically not contain an amino acid sequence that is unrelated to angiotensin function and/or processing, such as a lantibiotic leader peptide sequence. The size of a peptide analog can vary but ranges between 4 to 10 amino acids, as long as the "core" tetrameric segment comprising the 4-7 thioether-ring structure is encompassed. Preferred analogs contain 4- 8 amino acids, more preferably 5-8 amino acids. In a specific aspect, the analog consists of 7 amino acid residues, preferably corresponding to those of naturally occurring Ang(1-7).

The amino acid sequence of an analog of the invention can vary, as long as it is biologically active, either agonistically or antagonistically or can become proteolytically activated. Biological activity of an analog can be determined using methods known in the art, including radioligand binding studies, *in vitro* cell activation assays and *in vivo* experiments. See for example Koziarz et al., 1993 Gen. Pharmacol. 24, 705-713; Lemos et al 2005 J Cardiovasc Pharmacol 46, 274-279; Santos et al 2003 PNAS 100: 8258-8263; Godeny and Sayeski

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2006 Am J Physiol Cell Physiol.;291(6):C1297-307; Sarr et al., Cardiovasc Res. 2006 Sep 1;71(4):794-802; ; Silva et al 2007 Peptides 28, 702-707.

5   In one embodiment the invention provides a 4,7-cyclised analog designated [Cyc$^{4-7}$]Ang(1-10) derived from natural Angiotensin I (Ang(1-10).

In another embodiment the invention provides a 4,7-cyclised analog designated [Cyc$^{4-7}$]Ang(1-8) derived from natural Angiotensin II (Ang(1-8).

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In another embodiment the invention provides a 4,7-cyclised analog designated [Cyc$^{4-7}$]Ang(2-8) derived from natural Angiotensin III (Ang(2-8).

In another embodiment the invention provides a 4,7-cyclised analog designated

15   [Cyc$^{4-7}$]Ang(3-8) derived from natural Angiotensin IV (Ang(3-8).

In another embodiment the invention provides a 4,7-cyclised analog designated [Cyc$^{4-7}$]Ang(1-7) derived from natural Ang(1-7).

20   In another embodiment the invention provides a 4,7-cyclised analog designated [Cyc$^{4-7}$]Ang(1-9) derived from natural Ang(1-9).

The expression "derived from" is meant to indicate that the peptide sequence essentially corresponds to that of the naturally occurring linear Ang peptide.

25   As compared to the amino acid sequence of the natural angiotensin peptide, the amino acids at positions 4 and 7 of the [Cyc $^{4-7}$] analog are modified to allow introduction of the thioether-ring structure (see above). As will be understood, the amino acids at the other positions can be the same or they can be different, provided that the analog is biologically active. Preferably, besides

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the residues 4 and 7, zero, one or two residues are different from those found in the corresponding natural sequence, more preferably zero or one.

The function of the cyclic analog can be the same (e.g. agonist remains agonist) as or opposite to (e.g. agonist becomes antagonist) that of its linear counterpart. In case of analogs of inactive precursors, like [Cyc $^{4-7}$]Ang(1-10), biological function means both its susceptibility to (ACE-)enzymes that can convert it to a biologically active fragment (e.g. Ang(1-8) or Ang(1-7)) as well as the biological activity of the fragment itself.

Structure-activity relationships studies from several investigators have revealed the contribution of the individual amino acid residues to the activity of natural angiotensins (see Spyroulias et al. Eur. J. Biochem. 270, 2163, and references cited therein). These results can be used to predict to what extent a given amino acid can be altered in an analog of the present invention without loosing biological activity.

For example, it was found that the amino acid at position 1 in Ang(1-8) is not crucial for its activity, but that it is preferably a negatively charged amino acid, more preferably Asp.

The amino acid at position 2 is preferably a positively charged amino, preferably Arg.

The amino acid at position 3 is preferably an aliphatic residue, for example Ile or Val, preferably Val.

The amino acid at position 5 is preferably an aliphatic residue, for example Ile or Val, preferably Ile.

The amino acid at position 6 is preferably His, based on the finding that progressive destruction of the His^6 imidazole UV irradiation diminished Ang(1-8) activity (Samanen et al., J. Med. Chem. 31, 737-741).

The amino acid at position 8 in [Cyc$^{4-7}$]Ang(1-9) or at position 9 in [Cyc$^{4-7}$]Ang(1-10) is preferably other than Pro to allow for proteolytic activation.

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Poleyava et al. (Bioorg Med Chem. 2001 Jun;9(6):1639-47) disclosed that a
constrained cyclic Ang(1-8) analog with a lactam amide bridge linking a Lys-
Glu pair at positions 3 and 5 and possessing Ile at position 8 is an inhibitor of
Ang(1-8). Thus, a [Cyc$^{4-7}$]analog of the invention can be designed having an

5   aliphatic residue at position 8, preferably Ile, to confer an inhibitory effect on
Ang(1-8) e.g. the analog [Cyc$^{4-7}$]Ang(1-8)F8I. To maintain the biological
activity of Ang(1-10), a Phe residue at position 8 is preferred.
For each of the analogs, the preferred amino acid at position 9 is His.
For each of the analogs, the preferred amino acid at position 10 is an aliphatic

10   residue, for example Ile, Val or Leu, of which Leu is preferred.
As will be understood, an analog may contain the above preferred residues for
each amino acid position in any combination.
Accordingly, the invention provides a cyclic angiotensin peptide analog
comprising a thioether-bridge linkage between the amino acids corresponding

15   to positions Tyr^4 and Pro^7 in the linear octapeptide Angiotensin II (Ang(1-8)),
said analog having the general formula [Cyc$^{4-7}$] Xaa$^{1-10}$, [Cyc$^{4-7}$] Xaa$^{1-9}$, [Cyc$^{4-7}$]
Xaa$^{1-8}$, [Cyc$^{4-7}$] Xaa$^{1-7}$, [Cyc$^{4-7}$] Xaa$^{2-8}$ or [Cyc$^{4-7}$] Xaa$^{3-8}$, wherein, if applicable,
         Xaa^1 is any amino acid, preferably a negatively charged amino acid,
         more preferably Asp;

20   Xaa^2 is a positively charged amino acid, preferably Arg;
         Xaa^3 is an aliphatic amino acid, such as Ile, Val, preferably Val;
         Xaa^5 is an aliphatic amino acid, such as Ile, Val, preferably Ile;
         Xaa^6 is His;
         Xaa^8 is other than Pro, preferably Phe;

25   Xaa^9 is other than Pro, preferably His;
         Xaa^{10} is an aliphatic amino acid, such as Ile, Leu, Val, preferably
         Leu.

The general formula [Cyc$^{4-7}$] Xaa$^{1-10}$ refers to a peptide consisting of amino

30   acids Xaa^1-Xaa^2-Xaa^3-Xaa^4-Xaa^5-Xaa^6-Xaa^7-Xaa^8-Xaa^9-Xaa^{10}, wherein the

peptide is cyclized via Xaa^4 and Xaa^7. Likewise, the general formula $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}7}$ refers to a peptide consisting of amino acids Xaa^1-Xaa^2-Xaa^3-Xaa^4-Xaa^5-Xaa^6-Xaa^7, wherein the peptide is cyclized via Xaa^4 and Xaa^7. Likewise, the general formula $[Cyc^{4\text{-}7}]$ $Xaa^{2\text{-}8}$ refers to a peptide consisting of amino acids Xaa^2-Xaa^3-Xaa^4-Xaa^5-Xaa^6-Xaa^7-Xaa^8, wherein the peptide is cyclized via Xaa^4 and Xaa^7.

In one embodiment, the peptide analog has the general formula $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}10}$, $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}9}$, $[Cyc^{4\text{-}7}]$ $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}8}$, $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}7}$, $[Cyc^{4\text{-}7}]$ $Xaa^{2\text{-}7}$, $[Cyc^{4\text{-}7}]$ $Xaa^{3\text{-}7}$, $[Cyc^{4\text{-}7}]$ $Xaa^{2\text{-}8}$ or $[Cyc^{4\text{-}7}]$ $Xaa^{3\text{-}8}$, wherein all but three, preferably all but two, more preferably all but one of the residues other than Xaa^4 and Xaa^7 are identical to those found in naturally occurring Ang(1-10), i.e. wherein Xaa^1 is Asp, Xaa^2 is Arg, Xaa^3 is Val, Xaa^5 is Ile, Xaa^6 is His, Xaa^8 is Phe, Xaa^9 is His, Xaa^{10} is Leu. In a specific aspect, the peptide analog has the general formula $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}10}$, $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}9}$, $[Cyc^{4\text{-}7}]$ $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}8}$, $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}7}$, $[Cyc^{4\text{-}7}]$ $Xaa^{2\text{-}7}$, $[Cyc^{4\text{-}7}]$ $Xaa^{3\text{-}7}$, $[Cyc^{4\text{-}7}]$ $Xaa^{2\text{-}8}$ or $[Cyc^{4\text{-}7}]$ $Xaa^{3\text{-}8}$, wherein Xaa^1 is Asp, Xaa^2 is Arg, Xaa^3 is Val, Xaa^5 is Ile, Xaa^6 is His, Xaa^8 is Phe, Xaa^9 is His, Xaa^{10} is Leu.

In a preferred embodiment, the peptide has the general formula $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}7}$. As is shown herein below, this Ang(1-7) analog has Ang(1-8) antagonistic and Ang(1-7) agonistic activity, combined with an increased proteolytic resistance when compared to unmodified, linear Ang(1-7). Thus far, no conformationally constraint analogs of Ang(1-7) have been described. The present finding that it is possible to modify two out of seven amino acids (i.e. a change in nearly 30% of the side chains) without losing biological activity is unexpected. What is more, the increased resistance towards proteolytic enzymes upon introduction of the 4,7-thioether ring could not be anticipated.

In a peptide analog according to the general formula $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}10}$, $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}9}$, $[Cyc^{4\text{-}7}]$ $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}8}$, $[Cyc^{4\text{-}7}]$ $Xaa^{1\text{-}7}$, $[Cyc^{4\text{-}7}]$ $Xaa^{2\text{-}7}$, $[Cyc^{4\text{-}7}]$

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Xaa$^{3-7}$, [Cyc$^{4-7}$] Xaa$^{2-8}$ or [Cyc$^{4-7}$] Xaa$^{3-8}$, the residues Xaa^4 and Xaa^7 together form a thioether-bridge. Preferably, Xaa^4 is a D-stereoisomer and/or Xaa^7 is a L- stereoisomer. More preferably, Xaa^4 is a D-stereoisomer and Xaa^7 is a L- stereoisomer. The thioether bridge is for instance in accordance with formula

5   A, B or C as indicated above. Formula A is preferred.

In one embodiment, the amino acids at positions 4 and 7 are independently selected from Abu (2-aminobutyric acid) and Ala (alanine), with the exception of Abu being present at both positions 4 and 7. Thus, encompassed are cyclic analogs comprising a thioether linkage formed by –

10   Ala^4-S-Ala^7-(Formula A: R, R^1, R^2 and R^3 being H); –Ala^4-S-Abu^7- (Formula A: R, R^1 being H, one of R^2 and R3 being H and the other being CH$_3$) or –Abu^4-S- Ala^7- (Formula A: one of R and R^1 being H the other being CH$_3$, R^2 and R^3 being H). Specific cyclic analogs comprise a –Abu^4-S-Ala^7- or Ala^4-S-Ala^7- linkage (see also Figure 7).

15

In a specific aspect, the angiotensin analog is selected from the group consisting of the following 4,7-thioether cyclised peptides:

the [Cyc$^{4-7}$]Ang(1-10) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Phe-His-

20   Leu

the [Cyc$^{4-7}$]Ang(1-9) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Phe-His

the [Cyc$^{4-7}$]Ang(1-8) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala -Phe

25

the[Cyc$^{4-7}$]Ang(1-8) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Ile

the [Cyc$^{4-7}$]Ang(1-7) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala

30   the [Cyc$^{4-7}$]Ang(2-7) analog Arg-Val-Abu/Ala-Ile-His-Abu/Ala

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under the provision that Abu is not present simultaneously at positions 4 and 7. In other words, the peptide does not contain two Abu (2-aminobutyric acid) residues.

5

In a preferred aspect, the analog is selected from the group consisting of the [Cyc⁴⁻⁷]Ang(1-10) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Phe-His-Leu, the [Cyc⁴⁻⁷]Ang(1-9) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Phe-His the [Cyc⁴⁻⁷]Ang(1-8) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Ile,

10   the [Cyc⁴⁻⁷]Ang(1-7) analog Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala and the [Cyc⁴⁻⁷]Ang(2-7) analog Arg-Val-Abu/Ala-Ile-His-Abu/Ala.

In particular, provided is an Ang(1-7) analog with a thioether-bridge between position 4 and position 7 having the amino acid sequence Asp-Arg-Val-Abu-Ile-

15   His-Ala, Asp-Arg-Val-Ala-Ile-His-Abu or the amino acid sequence Asp-Arg-Val-Ala-Ile-His-Ala. These analogs antagonize constriction in the trachea smooth muscle by natural angiotensin(1-8). This activity appeared comparable to that of the natural linear Ang(1-7) peptide, DRVYIHP. It was surprisingly found that these analogs also cause vasodilation of phenylephrine-induced

20   vasoconstriction in aorta from Sprague Dawley rats, indicating that the ring introduction preserves Ang(1-7) receptor agonistic activity.

Modification of the Pro residue at position 7 of linear Ang(1-7) has been described in the art. Santos et al. (Proc Natl Acad Sci USA 2003; 100:8258–

25   63).demonstrated that Ang(1-7) peptide wherein the original Pro residue at position 7 is replaced by D-Ala is converted into an Ang(1-7) receptor antagonist. Another study (Da Silva *et al.* Peptides 28 (2007), 702-707) likewise shows that a mutant, linear Ang(1-7) peptide wherein the original L-Pro at position 7 is replaced by D-Pro acts in Sprague Dawley rats, as an

30   Ang(1-7) receptor antagonist, likely of a different Ang(1-7) receptor than in the

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above study of Santos et al which involves Chinese Hamster Ovary cells. In view of these published data, the present finding that Ang(1-7) agonist activity is preserved upon introduction of a substantive modification at position 7 in 4,7-cyclic Ang(1-7) is therefore highly surprising.

5

In a still further embodiment, an angiotensin(1-8) analog is provided having Ang(1-8) receptor antagonistic activity and having the sequence Asp-Arg-Val-Abu-Ile-His-Ala-Ile.

10   Also provided is a pharmaceutical composition comprising a 4,7-cyclised angiotensin analog of the invention, or a pharmaceutically acceptable salt or complexes thereof, and a pharmaceutically acceptable carrier

As used herein, "acceptable salt" refers to salts that retain the desired activity of the peptide or equivalent compound, but preferably do not
15   detrimentally affect the activity of the peptide or other component of a system, which uses the peptide. Examples of such salts are acid addition salts formed with inorganic acids, for example, hydrochloric acid, hydrobromic acid, sulfuric acid, phosphoric acid, nitric acid, and the like. Salts may also be formed with organic acids such as, for example, acetic acid, oxalic acid, tartaric acid,
20   succinic acid, maleic acid, fumaric acid, gluconic acid, citric acid, malic acid, ascorbic acid, benzoic acid, tannic acid, pamoic acid, alginic acid, polyglutamic acid, and the like. Salts may be formed with polyvalent metal cations such as zinc, calcium, bismuth, barium, magnesium, aluminium, copper, cobalt, nickel and the like or with an organic cation formed from N,N'-
25   dibenzylethylenediamine or ethylenediamine, or combinations thereof (e.g., a zinc tannate salt). The non-toxic, physiologically acceptable salts are preferred.

The salts can be formed by conventional means such as by reacting the free acid or free base forms of the product with one or more equivalents of the appropriate acid or base in a solvent or medium in which the salt is insoluble,
30   or in a solvent such as water which is then removed *in vacuo* or by freeze-

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drying, or by exchanging the cations of an existing salt for another cation on a suitable ion exchange resin.

In one aspect, the invention provides a method for the treatment or prophylaxis of a disease involving unwanted vasoconstriction, comprising

5   administering to a subject in need thereof a therapeutically effective dose of an angiotensin analog according to the present teachings having Ang(1-8) antagonistic activity, or a pharmaceutically acceptable salt or complexes thereof. The subject is preferably a human subject, for example a human hypertensive or asthmatic subject.

10 Preferably, the composition comprises a cyclized analog having Ang(1-8) receptor antagonistic and/or Ang(1-7) receptor agonistic activity. Thus, an analog may have Ang(1-8) antagonistic activity e.g. by blocking the Ang(1-8) receptor and/or it may have Ang(1-7) agonistic activity, e.g. by binding to an Ang(1-7) receptor, in particular the Mas-receptor, in combination with

15 subsequent signal transmission. Ang(1-8) antagonistic activity does not necessarily imply Ang(1-7) agonistic activity, and vice versa.

The person skilled in the art will be able to determine whether an analog of the invention possesses Ang(1-8) antagonistic or agonistic activity using

20 methods known in the art. As shown herein below, trachea rings of guinea pigs can be used to determine the capacity of an analog to induce contraction of the trachea smooth muscle (indicative of agonistic activity) or the capacity of an analog to inhibit contraction of the trachea smooth muscle induced by "normal" Ang(1-8), which is indicative of antagonistic activity. Also it is shown that

25 aorta rings of Sprague-Dawley rats can be used to determine the capacity of an Ang(1-7) analog to induce dilatation of phenylephrine-induced contraction. Other types of assays, for instance *in vitro* cell activation assays, can also be of use to determine the pharmacological properties of an angiotensin analog. *In vivo*, the effect of Ang(1-7) analogue on blood pressure reduction can be

30 measured effectively after intravenous injection of the analog.

20

Ang(1-7) receptor agonistic activity is preferably defined as being capable of dilating isolated aorta rings that are precontracted with phenylephrine. In a particular aspect, there is provided a pharmaceutical composition comprising a 4,7-cyclised angiotensin analog of the invention, or a

5   pharmaceutically acceptable salt or complexes thereof, and a pharmaceutically acceptable carrier, wherein said analog displays a vasodilating effect that is at least 1.2 times stronger as compared to naturally occurring Ang(1-7) as determined using isolated aorta rings preconstricted by incubation with $10^{-7.5}$ M phenylephrine.

10

As will be understood, any known or yet to be discovered therapeutic or prophylactic use of naturally occurring Ang(1-7) will benefit from the present finding that a more stable analog can be prepared which has an Ang(1-7) -like activity. Useful applications of an Ang(1-7) analog (i.e. a 4,7-cyclized peptide

15   having Ang(1-7) receptor agonistic activity) provided herein include treatment of hypertension and treatment of unwanted trachea constriction. Other useful applications are tissue repair, protection of bone marrow against cytostatica, antitumor applications and anti-inflammatory applications.

20   In a specific aspect, the invention relates to the use of a 4,7-cyclized peptide analog having Ang(1-7) receptor agonistic activity to accelerate wound healing. As indicated above, both Ang(1-7) and Ang(1-8) are capable of inducing tissue repair. However, Ang(1-7) and analogs thereof are less potent than Ang(1-8) at inducing hypertension. Such analog advantageously forms the basis of

25   compositions useful for accelerating wound healing, the compositions comprising at least one analog effective to accelerate wound healing. Preferably, the compositions are in the form of matrical or micellar solutions. The cyclic Ang(1-7) analog may be administered in conjunction with a wound dressing. Provided is a method for accelerating re-epithelialization of wound

30   tissue in a mammal, comprising applying to said wound tissue an amount of a

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4,7-cyclized peptide analog having Ang(1-7) receptor agonistic activity effective
for said acceleration.

According to a method of the invention, a 4-7-cyclized Ang(1-7)
analog in accordance with the present invention, such as an Ang(1-7) analog
5   with a thioether-bridge between position 4 and position 7 having the amino
acid sequence Asp-Arg-Val-Abu-Ile-His-Ala, Asp-Arg-Val-Ala-Ile-His-Abu or
the amino acid sequence Asp-Arg-Val-Ala-Ile-His-Ala, is applied to wound
tissue in amounts sufficient to increase the healing rate of tissue. This analog
can significantly accelerate the rate of healing at nanomolar levels in vivo. For
10   any given active agent, the optimum concentration for a given formulation
may readily be determined empirically. In general, an amount of active agent
suitable for use in accordance with the present invention ranges from about
0.0001 µg to about 10 mg per kilogram body weight.

The analogs of the invention may be applied in a variety of solutions.
15   Suitable solutions for use in accordance with the present invention are sterile,
dissolve sufficient amounts of the peptide, and are not harmful to wound
tissue.

Any type of application means may be employed which permits the
influx of the active analog into the tissue over a period of time. For example,
20   an aqueous solution could be applied to the wound tissue through a gauze
bandage or strip, or such a solution could be formulated so that a timed
perfusion may be obtained (using, e.g., liposomes, ointments, micelles, etc).
Methods for the production of these formulations with the analogs of the
present invention are apparent to those of ordinary skill in the art. The
25   particular concentration of active agent employed is not critical, as the tissue-
repairing effect may be observed even when the analogs are present in
nanomolar quantities. Preferably, a matrical or micellar solution is employed
with the active angiotensin analog present in a concentration of at least 30
micrograms per milliliter. A particular matrical solution which has been used
30   to advantage in the described examples is a semi-solid polyethylene glycol

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polymer sold under the trademark Hydron by Hydro Med Sciences, New Brunswick, N.J. Another preferred solution is a micellar solution sold under the trade name Pluronics F108 by BASF, Ludwigshafen, Germany. Under room temperature conditions, this solution is a liquid, but when applied to

5   warm tissue the solution forms a gel which permits the infusion of active agent into the wound tissue for a period of several days. Other preferred formulations include carboxymethyl cellulose preparations (as used in the example herein), crystalloid preparations (e.g., saline, Ringer's lactate solution, phosphate-buffered saline, etc.), viscoelastics, polyethylene glycols,

10   polypropylene glycols and wound dressings (e.g., bandages, etc.). The solution may be applied topically to surface wound tissue in the treatment of ulcers, lesions, injuries, diabetic ulcers, burns, trauma, stasis ulcers, periodontil conditions, lacerations and other conditions. In addition, intraperitoneal wound tissue such as that resulting from invasive surgery may be treated with

15   a composition in accordance with the present invention to accelerate healing. For example, following the surgical removal of a colon section or other tissue, the surgical plane may be coated with a solution of active cyclic analog prior to closing the surgical site in order to accelerate internal capillary perfusion and healing. In addition, the rate of localized healing may be increased by the

20   subdermal administration of active agent by injection or otherwise.

A further specific application of a cyclic Ang(1-7) receptor agonist according to the invention relates to preventing restenosis. It has been shown that Ang(1-7) receptor agonists can be used to preventing restenosis after vascular stent

25   implantation by delivering them to the treatment site (see e.g. WO2006047289). Another useful application of a stable, 4,7- cyclised analog of the invention having Ang(1-7) receptor agonist activity therefore relates to suppression of vascular smooth muscle cell proliferation by delivering to the treatment site one or more agonists of the angiotensin(1-7) receptor. For

30   example, the present invention provides a drug-eluting medical device, in

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particular a vascular stent, with a coating of cyclised angiotensin(1-7) analog-containing controlled-release polymer. Additionally the present invention provides the use of at least one 4,7-cyclized angiotensin analog having Ang-(1 - 7) receptor agonist in the manufacture of a medicament for treating impaired

5   vascular endothelial cell function in a mammal, wherein said medicament is released from a surface of an implantable medical device. For example, provided is a vascular stent provided with a 4,7 cyclic Ang(1-7) analog having the amino acid sequence Asp-Arg-Val-Abu-Ile-His-Ala, Asp-Arg-Val-Ala-Ile-His-Abu or the amino acid sequence Asp-Arg-Val-Ala-Ile-His-Ala.

10

Also provided herein is the use of an angiotensin analog according to the present teachings having Ang(1-8) receptor antagonistic activity or a pharmaceutically acceptable salt or complexes thereof for the manufacture of a medicament for the treatment of a disease involving unwanted

15   vasoconstriction. In one embodiment, the Ang(1-8) antagonist is a 4,7-cyclised Ang(1-7) analog as provided herein. In another embodiment, the Ang(1-8) antagonist is a 4,7-cyclised Ang(1-8) analog having an aliphatic residue at position 8 (preferably Ile) as provided herein. There are several diseases wherein unwanted vasoconstriction or unwanted constriction of the trachea

20   occurs. For example, the invention provides the use of a [Cyc$^{4\text{-}7}$] analog having AngII antagonistic activity for the treatment of hypertension or heart failure. Another example is the use of 4,7 cyclised Ang(1-7) or an antagonistic 4,7 cyclised angiotensin(1-8) for the treatment of asthma or other cases of unwanted constriction of the trachea.

25   The AngII antagonists are also of value in the management of acute and chronic congestive heart failure, in the treatment of secondary hyperaldosteronism, primary and secondary pulmonary hyperaldosteronism, primary and secondary pulmonary hypertension, renal failure, renal vascular hypertension, ocular hypertension and impaired retinal blood flow, and in the

30   management of vascular disorders such as migraine or Raynaud's disease. The

24

application of the analogs of this invention for these and similar disorders will be apparent to those skilled in the art.

In the management of hypertension and other clinical conditions, the analogs of this invention may be utilized in compositions such as tablets,

5   capsules or elixirs for oral administration, suppositories for rectal administration, sterile solutions or suspensions for parenteral or intramuscular administration, and the like. The peptide may also be administered via dry or liquid inhalation sprays into the lung. This route of administration is of particular interest for bronchi dilation. However, it is also

10   suitable for systemic delivery of the peptide. (reviewed by Gonda, J Aerosol Medicine 19;47-53 (2006)).

The analogs according to the invention can be administered to patients (animals and human) in need of such treatment in dosages that will provide optimal pharmaceutical efficacy. Although the dose will vary from

15   patient to patient depending upon the nature and severity of disease, the patient's weight, special diets then being followed by a patient, concurrent medication, and other factors which those skilled in the art will recognize, the dosage range will generally be about 1 to 1000 mg per patient per day which can be administered in single or multiple doses. Preferably, the dosage range

20   will be about 2.5 to 250 mg per patient per day; more preferably about 2.5 to 75 mg per patient per day.

The peptides according to the invention as well as pharmaceutically acceptable salt and complexes thereof are used for pharmacological purposes in the form of conventional pharmaceutical compositions. The term

25   "pharmaceutically acceptable complexes" of the peptides according to the invention is used herein to refer to complex compounds formed with certain, for instance organic materials, endowing the peptides with a retarded activity. Typical representatives of these compounds are gelatines, carboxymethylcelluloses, alginic acid esters, poly(fluoroethinephosphates),

30   amino acid polymers or other polymers and copolymers. As pharmaceutically

25

acceptable salts the conventional, pharmaceutically acceptable acid addition salts, e.g., acetates are used.

The pharmaceutical compositions contain the compounds according to the invention in admixture with organic or inorganic carriers suitable for
5   enteral or parenteral administration. Thus pharmaceutical compositions may be formulated as solid lyophilizates, in which various inert compounds not reacting with peptides, e.g., hydrocarbons can be used as carriers. When the pharmaceutical compositions are formulated as dilute or concentrated suspensions or emulsions, they contain also various preserving agents and
10 stabilizing agents.

Pharmaceutical compositions containing an analog according to the invention which has Ang(1-8) receptor antagonistic or Ang(1-7) receptor agonistic activity may be used for differentiated detection of renal hypertensions as well as for the treatment of every syndrome caused by an
15 increased renal blood pressure.

The compounds of this invention can also be administered in combination with other antihypertensives such as alpha -methyldopa, and/or diuretics such as hydrochlorothiazide, and/or angiotensin converting enzyme inhibitors such as enalapril, and/or calcium channel blockers such as
20 nifedipine and/or AngII receptor antagonists (AT1 or AT2-receptor antagonists). [Cyc^{4,7}]Ang(1-7) can also be applied in combination with Ang(1-8) antagonists. This is consequent to the fact that different receptors are involved. Ang(1-8) acts on AT1 or AT2 receptors, whereas Ang(1-7) acts on MAS receptor. Typically, the individual daily dosages for these combinations
25 can range from about one-fifth of the minimally recommended clinical dosages to the maximum recommended levels for the entities when they are given singly. These dose ranges can be adjusted on a unit basis as necessary to permit divided daily dosage and, and as noted above, the dose will vary depending on the nature and severity of the disease, weight of the patient,

special diets and other factors. Typically, these combinations can be formulated into pharmaceutical compositions as discussed below.

About 1 to 100 mg of an analog or a mixture of analogs or a physiologically acceptable salt thereof is compounded with a physiologically

5   acceptable vehicle, carrier, excipient, binder, preservative, stabilizer, flavor, etc., in a unit dosage form as called for by accepted pharmaceutical practice. The amount of active substance in these compositions or preparations is such that a suitable dosage in the range indicated is obtained.

10   Illustrative of the adjuvants which can be incorporated in tablets, capsules and the like are the following: a binder such as gum tragacanth, acacia, corn starch or gelatin; an excipient such as microcrystalline cellulose; a disintegrating agent such as corn starch, pregelatinized starch, alginic acid and the like; a lubricant such as magnesium stearate; a sweetening agent such

15   as sucrose, lactose or saccharin; a flavoring agent such as peppermint, oil of wintergreen or cherry. When the dosage unit form is a capsule, it may contain, in addition to materials of the above type, a liquid carrier such as fatty oil. Various other materials may be present as coatings or to otherwise modify the physical form of the dosage unit. For instance, tablets may be coated with

20   shellac, sugar or both. A syrup or elixir may contain the active compound, sucrose as a sweetening agent, methyl and propyl parabens as preservatives, a dye and a flavoring such as cherry or orange flavor.

Sterile compositions for injection can be formulated according to conventional pharmaceutical practice by dissolving or suspending the analog

25   in a vehicle such as water for injection, a naturally occurring vegetable oil like sesame oil, coconut oil, peanut oil, cottonseed oil, etc., or a synthetic fatty vehicle like ethyl oleate or the like. Buffers, preservatives, antioxidants and the like can be incorporated as required.

27

The Ang(1-8) receptor antagonistic analogs of this invention, e.g. 4,7-cyclised Ang(1-7) or the 4,7-cyclised Ang(1-8)Phe8Ile, are also useful to treat elevated intraocular pressure and can be administered to patients in need of such treatment with typical pharmaceutical formulations such as tablets,

5   capsules, injectables, as well as topical ocular formulations in the form of solutions, ointments, inserts, gels, and the like. Pharmaceutical formulations prepared to treat intraocular pressure would typically contain about 0.9% to 15% by weight, preferably 0.5% to 2% by weight, of a compound of this invention.

10

Another aspect of the invention relates to the use of stabilized Ang analogs of the invention for stimulating or activating young cells, for example bone marrow cells, cells involved in tissue repair and the like. It has been shown (see e.g. US 6,011,015) that Ang(1-8) or analogs thereof having Ang(1-8)

15   receptor agonistic activity can be used for promoting fertilization of mammalian eggs. In this type of application of angiotensin analogs, Ang(1-7) appears to act as an Ang(1-8) receptor agonist, rather than as Ang(1-8) receptor antagonist. Accordingly, an agonistic 4,7-cyclised angiotensin analog of the invention can be used for promoting fertilization of mammalian eggs,

20   especially human eggs. In particular, it provides the use of Ang(1-8) and Ang(1-7) analogs to improve sperm motility. The invention therefore also relates to a method of promoting *in vitro* fertilization of mammalian eggs, comprising adding a 4,7-cyclised Ang(1-8) or Ang(1-7) analog or a salt thereof to incubation medium containing oocytes and sperm.

25   A further application of cyclized analogs having Ang(1-8)-like activity relates to the transient stimulation of blood flow to a tumor or locally infected area by inducing vasoconstriction in the surrounding healthy tissue. This can be useful for targeted drug delivery at the affected site.

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Legends to the figures

Figure 1

5   **Comparison of native and thioether-ring-containing angiotensin with respect to protease resistance. Fig 1A: native (open circles) and lanthionine containing angiotensin(1-8) (filled squares) ; Fig 1B: native- (open circles) and lanthionine-containing (filled squares) angiotensin(1-7). Experimental details are mentioned in the text of example 1.**

10

Figure 2

Cyclized angiotensin(1-7) with thioether bridge between positions 4 and 7 is fully resistant against ACE.

15   A: Breakdown by 4 nM ACE of natural Ang(1-7) (open circles) or methyllanthionine-containing Ang(1-7) with the bridge between positions 4 and 7 (filled squares).

B: Formation of Ang(1-5) from natural Ang(1-7) (open circles) and from methyllanthionine-containing Ang(1-7) (filled squares) by incubation with 4

20   nM ACE.

C: Breakdown by 8 nM ACE of natural Ang(1-7) (open circles) or methyllanthionine-containing Ang(1-7) with the bridge between positions 4 and 7 (filled squares) or lanthionine-containing Ang(1-7) (open triangles).

D: Formation of Ang(1-5) from natural Ang(1-7) (open circles), from

25   methyllanthionine-containing Ang(1-7) (filled squares) or from lanthionine-containing Ang(1-7) (open triangles) by incubation with 8 nM ACE. The experiment depicted in Fig 2B corresponds to Fig 2A; while Fig 2D corresponds to Fig 2C, respectively.

        All points in Fig A-D are the average of two measurements. Linked to

30   the degradation of natural Ang(1-7) depicted in Fig 2A and Fig 2C, a

29

breakdown product, natural Ang(1-5) was formed. This breakdown product
was not formed in the case of thioether-ring-containing Ang(1-7). Experimental
details are mentioned in the text of example 2.

5   Figure 3
        In vivo stability of thioether-ring-containing angiotensin(1-7)
        demonstrated by maldi TOF spectra of plasma from rat
        simultaneously infused with natural Ang(1-7) and methyllanthionine
        containing Ang(1-7).

10   Rats (Sprague Dawley) were infused during 2 hours at a speed of 1 mL/hour
        with a solution containing simultaneously two compounds: both 100 μM
        natural Ang(1-7) as well as 100 μM methyllanthionine-containing
        angiotensin(1-7) with the thioether bridge between positions 4 and 7.
        Methyllanthionine-containing angiotensin(1-7) was prepared using L.lactis

15   expressing lantibiotic enzymes as described in example 1. Maldi TOF analyses
        were performed on plasma samples as described in example 3. Undiluted
        sample (upper spectrum, mass peak of 826.06 Da at the arrow) and 100-fold
        diluted sample (lower spectrum, mass peak of 826.47 Da at the arrow) both
        gave a peak of the right mass, i.e. corresponding to intact methyllanthionine-

20   containing angiotensin(1-7) (Theoretical mass M + H$^+$ equals 825.9758).
        Natural angiotensin(1-7) was not detected at all. In a control experiment
        mixing natural angiotensin(1-7) *ex vivo* with rat plasma, allowed subsequent
        detection of natural angiotensin(1-7) (not shown). Experimental details are
        mentioned in the text of example 3.

25

        Figure 4
        Cyclised Ang(1-7)-induced vasodilation of aortic rings.
        Vasodilating effect of naturally occurring Ang(1-7) and an Ang(1-7) analog
        with a thioether bridging position 4 (D-Ala) and 7(Ala) (a stereoisomer of

30   compound I in Fig 7), on aortic rings from Sprague Dawley rats.

30

Cross (×) represents a control; open circle: native Ang(1-7), filled square: thioether Ang(1-7). Each point represents the mean ± SEM of data derived from 4 rats. Experimental details are mentioned in the text of example 4.

5   Figure 5

Lowering of Ang(1-8)-induced trachea contraction by Ang(1-7) and cyclised Ang(1-7).

Contraction of trachea from guinea pigs induced by natural angiotensin(1-8) (cross, ×), by natural angiotensin(1-8) after addition of natural angiotensin(1-

10   7) (open circles) and by natural angiotensin(1-8) after addition of lanthionine-containing angiotensin(1-7) with the thioether between positions 4 and 7 (filled squares). Values are the means of 4 independent experiments. Experimental details are mentioned in the text of example 5.

15   Figure 6A

Effect of natural Ang(1-7) and cyclized Ang (1-7) (cAng(1-7))

intravenous bolus injections on mean arterial blood pressure (MAP).

Saline pretreatment (white bars) and antagonist A799 pretreatment (black bars). Tested: 5-8 mice.

20

Figure 6B

Effect of natural Ang(1-7) and cyclized Ang(1-7) (cAng(1-7))

intravenous bolus injections on recovery of mean arterial blood

pressure (MAP) to pretreatment level. Saline pretreatment (white bars)

25   and Ang(1-7) antagonist A799 pretreatment (black bars). *$P<0.05$ vs. Ang-(1-7) saline group. Tested: 5-8 mice.

<u>Figure 7</u>

Lanthionine- and methyllanthionine analogs of angiotensin(1-7) with the

5   thioether bridging positions 4 and 7 ([Cyc$^{4-7}$] Ang(1-7); *compounds C, F and I*),

angiotensin(1-8) ([Cyc$^{4-7}$] Ang(1-8); *compounds A, D and G*) and angiotensin

F8I angiotensin(1-8) ([Cyc$^{4-7}$] Ang(1-8)F8I; *compounds B, E and H*).

Conventional one-letter code is used to indicate the amino acid at each

position. Abu is 2-aminobutyric acid. Lanthionine is Ala-S-Ala,

10   methyllanthionine is Abu-S-Ala or Ala-S-Abu. The sulfur atom in each

structure may be oxidized once or twice.

The invention is further illustrated by the following examples.

15

Example 1 : Introduction of a thioether ring between position 4 to
position 7 enhances the proteolytic resistance of angiotensin(1-8) and
angiotensin(1-7).

20   Naturally occurring angiotensin(1-8) and angiotensin(1-7) are linear peptides

with a short half-life as a result of rapid proteolytic breakdown. This example

describes the introduction of a thioether-ring in Ang(1-7) and in Ang(1-8)

between amino acids corresponding to positions 4 and 7 in Ang(1-8), i.e. Tyr^4

and Pro^7, resulting in [Cyc$^{4-7}$]Ang(1-7) having the sequence Asp-Arg-Val-Ala-

25   Ile-His-Ala (compound *I* in Fig. 7) and [Cyc$^{4-7}$]Ang(1-8) having the sequence

Asp-Arg-Val-Abu-Ile-His-Ala-Phe (compound *A* in Fig. 7), respectively.

Using homogenates of pig organs comprising several types of proteolytic

enzymes, an enhanced resistance against enzymatic breakdown of [Cyc^{4-}

^{7}]Ang(1-8) and [Cyc$^{4-7}$]Ang(1-7) is demonstrated as compared to their non-

30   cyclised, linear counterparts.

Experimental procedure

Cyclized Ang(1-7) was produced both biologically and chemically, while
5   cyclized Ang(1-8) was produced biologically.

Biological production of [Cyc$^{4-7}$]Ang(1-8) and [Cyc$^{4-7}$] Ang(1-7).

The production of cyclic angiotensin(1-8) and angiotensin(1-7) analogs
containing a 4,7- (methyl)lanthionine thioether ring, [Fig 7: compounds A, B,
10   C, G, H, I] was started by designing oligonucleotides which encode the
respective peptides. The amino acid at position 4 was Thr or Ser, while
position 7 was Cys. The genetic code for the respective angiotensins was fused
behind the coding sequence for the leader peptide from nisin and the N-
terminal part of the nisin peptide (17-21 aa). When considering the peptide
15   production level on the one hand and the extent of dehydration/thioether ring
formation on the other, this fusion procedure proved to give the best results
(instead of for instance direct fusion behind the leader peptide). A proteolytic
cleavage site was introduced enabling liberation of the angiotensin from the
fused nisin part (i.e. trypsin (Arg/Lys) or Factor Xa (IEGR).

20   The genetic code for the angiotensin-containing fusion peptide including
Factor Xa site: Leader peptide-
ITSISLCTPGCKTGALMIEGR<u>DRV[T/S]IHC(F)</u> was placed on a rolling circle
plasmid, under the control of the nisin promoter and, in the presence of a
second plasmid (theta replication) comprising the maturation genes *nisB* and
25   *nisC*, as well as the transporter gene *nisT* under the same promoter, produced
by the host organism *Lactococcus lactis*, strain NZ9000.

From an overnight (o/n) preculture in rich GM17 medium 1/50 of volume
was transferred to MM medium (see Kluskens et al., 2005) supplied with 0.12
M MOPS (filter sterile). Immediate induction with nisin was performed,
30   followed by growth o/n (16 – 18 h). Supernatant was obtained by centrifugation

33

(10.000 rpm, 20 min, 8°C) and subsequently filtered (0.2 µm). The supernatant was diluted (1: 1) with wash buffer (50 mM lactic acid), and the 1 L in total was reduced in volume by running it over a 5 mL ion-exchange-chromatography column (HiTrap, Amersham) by 5 mL/min. After washing

5   with 5 volumes of wash buffer, the peptide was eluted with elution buffer (50 mM lactic acid, 1 M NaCl). The peptide elutes between 5 and 10 ml in general.

    The eluted peptide (e.g. 5 mL) was desalted using PD10 columns (Amersham) which typically results in 7 mL desalted peptide in solution. This was freeze-dried o/n, which in general results in an amount of approx. 10

10   mg dry weight per liter.

    The fusion peptide was then enzymatically cleaved to release the peptide from leader-nisin fragment, using one of the enzymes mentioned earlier. Usually, 5 mg of dried fusion peptide was cleaved using 5-10 Units of enzyme (enterokinase, Factor Xa) or 5 ug Trypsin per ml reaction volume.

15   Cleavage was carried out o/n at 23°C (Factor Xa), or 4-6 h at 37°C when trypsin was used. All reactions were carried out in a Tris buffer (100 mM Tris, pH 8.0, 100 mM NaCl, 2 mM CaCl$_2$).

    Purification of the enzymatically cleaved peptide was performed by HPLC, using a reversed-phase column (C18). Sample was applied in a total

20   volume of 200 µL, which contains 10 % acetonitril (ACN) / 0.1 %TFA. With a gradient of 10 to 90 % ACN the peptide was separated from the other peptide fragments. Sample, when pure, was then vacuum-dried and the protein concentration was determined using the Lowry method, and compared to a standard curve of BSA or a short, more similar peptide.

25   Ser/Thr dehydration was observed by a mass shift of -18 Da, when examined by Maldi-TOF mass spectrometry. In addition, ethanethiol additions were used, in which free dehydroresidues reacted with ethanethiol, resulting in a mass shift of + 62 Da/dehydroresidue.

    The presence of a thioether ring was proven by absence of chemical

30   addition of CDAP (1-cyano-4-dimethylaminopyridinium tetrafluoroborate),

34

which, in the case of absence of a ring, will react with available cysteine residues, that do not participate in thioether rings, and subsequently will result in a mass shift of + 25 Da.

For the biological production of an Ang(1-8) analog ending with a

5   Isoleucin at position 8 according to the above procedure, it is advantageous to modify the amino acids at positions 3 (Val) and/or 5 (Ile) in order to obtain correct dehydration and ring formation. Val3 found in the natural Ang(1-8) sequence may be replaced by Ile. Ile5 found in the natural Ang(1-8) sequence may be replaced by Val. Possible useful peptide sequences include DRITVHCI

10   and DRITIHCI.

Chemical production of [Cyc$^{4-7}$]Ang (1-7)

The following peptide was synthesized : H-Asp-Arg-Val-(D-)-Cys-Ile-His-Cys-OH. Thioether formation (lanthionine) was performed as described by

15   Galande et al. ((2003) Biopolymers 71(5), 534-551). Briefly, 11.5 mg of a crude peptide preparation, which was approximately 50% pure, was dissolved in 10 mL milliQ that was saturated with N₂ (g). 5 droplets of 25% NH₄OH were added and the solution was incubated in a 15 mL Greiner tube at 37 °C for 40 hours. The solution was dried in a speed-vac to remove the ammonia, and

20   subsequently dissolved in milliQ containing 0.2 % trifluoroacetic acid. The thioether peptide (Asp-Arg-Val-Ala-Ile-His-Ala; thioether bridge 4-7) was purified by reverse-phase HPLC on a C18 column with a gradient of milliQ (0.1 % TFA) and acetonitril (0.1 % TFA). The peak corresponding to the expected mass of 811 Da was collected and dried and dissolved in milliQ. The peptide

25   concentration was determined by Lowry using BSA as standard. A total of 1.9 mg of thioether ring-containing peptide was obtained.

35

Natural (i.e. linear) Ang(1-8) peptide was obtained from Sigma (St Louis, MO, USA) and natural Ang(1-7) from Bachem AG, Bubendorf, Switserland as ready-to-use compounds.

5   *Measurements on the proteolytic resistance.*
Angiotensin (wildtype or cyclised analogs, chemically produced [Cyc [4-7]] Ang(1-7) or biologically produced [Cyc [4-7]] Ang(1-8)) was added to homogenates of pig liver (0.2 μmol angiotensin / mg liver homogenate), pig kidney (0.2 μmol angiotensin / mg kidney homogenate), pig pancreas (0.8 μmol angiotensin / mg

10 pancreas homogenate) or plasma (1 μmol angiotensin/ml) and incubated at 37°C, pH 7.4 or pH 5, for different time periods up to 30 hours. The enzymatic reaction was stopped by 100 °C for 5 min. The remaining amount of intact angiotensin was determined by RP-HPLC with C18-column, mobile phase gradient and 214 nm detection.

15

Results
Introduction of a thioether ring between position 4 and 7 resulted in a higher stability of angiotensin(1-8) and angiotensin(1-7) in all of the tested homogenates. Introducing the 4,7 thioether bridge in Ang(1-8) significantly

20 increased its half-life in liver, kidney or pancreas homogenate at pH 7.4.

Ang(1-7) stability was measured at pH 7.4 as well as pH 5, the latter pH mimicking the lysosomal pH. At pH 7.4, the half-life of angiotensin(1-7) increased 2 (liver), 6 (kidney) and more than 18 (pancreas) fold by 4,7-cyclisation. At pH 5, in liver homogenate, ring introduction increased the half-

25 life 5-fold. (Tables 1A, 1B; Figures 1 A and 1B).

36

Table 1

A) Ang(1-8)

homogenate	pH	Degradation after 3 h (%)		Half-life (min)	
		linear	Cyc$^{4-7}$	linear	Cyc$^{4-7}$
Liver	7.4	98	100	36	67
Kidney	7.4	100	100	1.5	7
Pancreas	7.4	70	21	104	483

B) Ang(1-7)

homogenate	pH	Degradation after 3 h (%)		Half-life (min)	
		linear	Cyc$^{4-7}$	linear	Cyc$^{4-7}$
Liver	7.4	100	82	32	68
	5.0	56	8	153	708
Pancreas	7.4	81	4	81	> 24 hours
	5.0	16	6	∞	∞
Kidney	7.4	100	91	5	32
	5.0	98	4	28	> 24 hours
Plasma	7.4	55	15	166	926

Conclusion

4,7-cyclised analogs of Ang(1-7) and Ang(1-8) show a significantly enhanced resistance against enzymatic breakdown as compared to their natural, linear counterparts.

Example 2. Thioether-ring-containing angiotensin is fully resistant against ACE.

In vivo, ACE contributes strongly to breakdown of natural angiotensin(1-7) by cleavage of the peptide between the amino acids at positions 5 and 6. In view of the thioether bridge between positions 4 and 7 in the cyclised analogs of the invention, we hypothesised that the thioether bridge confers resistance against proteolytic degradation. In this example we

37

investigated *in vitro* the resistance of angiotensin with and without thioether ring against angiotensin converting enzyme (ACE).

Methods. Angiotensin Converting Enzyme (ACE) from Porcine kidney, SIGMA,
5   was used at 4 nM final concentration, FIG 2A and 2B, or at 8 nM final concentration, FIG 2C and 2D. Natural Ang(1-7) was purchased from Bachem. All experiments were performed in duplicate in a waterbath at 37 °C, incubations were performed in a buffer containing 100 mM Tris-HCl, 300 mM NaCl, 10 µM Zn, pH 8.3. Thioether-ring-containing angiotensin was obtained
10   by bacterial production using *L. lactis* containing the nisin modification and transporter enzymes, NisBTC. Natural angiotensin(1-7), lanthionine-containing angiotensin(1-7) and methyllanthionine-containing angiotensin(1-7) were each used at a concentration of 50 µM. Both the lanthionine and the methyllanthionine variant had the thioether bridge between positions 4 and 7.
15   The reaction was stopped by 100 °C for 5 minutes and put on ice. Samples were centrifuged for 10 min at 14000 rpm at 4 °C and quantified by RP-HPLC. Identification of the HPLC peaks was performed using Maldi TOF mass spectrometry. All points are the average of two measurements.

20   Results. FIG 2A demonstrates that after 26 hour of incubation with 4 nM ACE, no degradation of the methyllanthionine variant has occurred (filled squares) while the natural angiotensin(1-7) is completely broken down (open circles). Breakdown of natural angiotensin(1-7) by ACE resulted in angiotensin(1-5) formation (Fig 2B, open circles). Incubation of thioether angiotensin(1-7) with
25   ACE did not lead to the appearance of Ang(1-5) (filled squares on the x-axis in Figures 2B and 2D). Even at a two fold higher ACE concentration, no breakdown of the thioether-bridged angiotensin analogs is observed (Fig 2C, filled squares and open triangles) while natural angiotensin is rapidly broken down (Fig 2C, open circles). Again, breakdown of natural angiotensin(1-7)
30   coincides with the emergence of angiotensin(1-5), the primary breakdown

38

product following ACE activity (Fig 2D, open circles). No appearance of Ang(1-5) is observed after incubation of thioether angiotensin(1-7) with ACE (Fig. 2D filled squares and open triangles). These data demonstrate an exceptional resistance of the thioether-bridged angiotensin analogs.

5

Example 3: Thioether-ring-containing Ang(1-7) is highly stable *in vivo*.
In this example we studied peptide stability during continuous intravenous

10   infusion in the rat. It is demonstrated that a thioether ring in Ang(1-7) bridging positions 4 and 7 also confers proteolytic resistance *in vivo*, while the corresponding linear angiotensin without thioether ring is rapidly degraded.

Experimental

15   A male Sprague Dawley rat was kept under O_2/Isoflurane (1.5-2 %) narcosis throughout the study. A jugular vein catheter was applied and connected to a syringe containing 0.9% physiological salt solution. The syringe was mounted onto an infusion pump and the flow rate set to 1 mL/hour. In the meantime a carotic artery catheter was applied and connected to a syringe containing 0.9 %

20   physiological salt solution. The rat was than heparinized via an injection in the penis vein. After 30 minutes the infusion pump syringe was replaced with a syringe containing a mix of 100 μM native Ang(1-7) and 100 μM methyllanthionine-containing Ang(1-7) analog. The flow rate was set at 1 mL/hour. Blood was sampled via the carotic artery. The blood samples were

25   centrifuged 5 minutes at 13.000 RPM at 4 °C to obtain plasma. 5 μL plasma was added to 45 μL MQ water. The mixture was boiled 5 min, then put on ice for 10 min. After this the mixture was centrifuged for 10 min at 14000 rpm in an Eppendorf centrifuge, after which the supernatant was dried in a speed vac, resuspended in a few μl and added to the Maldi target for Maldi TOF analysis.

30

Results

39

Thioether cyclised angiotensin was detected in the sample taken at 120 min.
Undiluted sample (Fig 3, upper spectrum, mass peak of 826.06 Da at the
arrow) and 100-fold diluted sample (Fig 3, lower spectrum, mass peak of
826.47 Da at the arrow) both gave a peak of the right mass, i.e. corresponding

5   to intact methyllanthionine-containing angiotensin(1-7). Theoretical mass M +
H⁺ equals 825.98. Natural angiotensin(1-7) was not detected at all. A control
experiment in which natural angiotensin(1-7) was mixed *ex vivo* with rat
plasma, allowed subsequent detection of natural angiotensin(1-7) (not shown).
These data demonstrate that *in vivo* the thioether-bridged angiotensin(1-7) is

10   very stable, while the natural angiotensin(1-7) is rapidly and completely
broken down.

Conclusion

These data demonstrate a prolonged lifetime of the cyclised thioether Ang(1-7).
15   The higher plasma levels provide the thioether peptide with a better
bioavailability, and thus an increased therapeutic potential.

20

**Example 4. Thioether-ring-containing angiotensin(1-7) more
effectively causes vasodilation than natural angiotensin(1-7).**

25   This example demonstrates the Ang(1-7) agonistic activity of thioether-ring-
containing angiotensin(1-7) with the ring from position 4 to 7. In endothelium
intact aorta rings from Sprague Dawley rats that are precontracted with
phenylephrine, thioether ring containing angiotensin(1-7) causes dilation in a
concentration-dependent manner and more effectively than the natural

30   angiotensin(1-7).

40

<u>Experimental</u>

Aortic rings of male Sprague Dawley rats were used for isometric measurements of contraction and vasodilation. The rings were kept under a isometric tension of 1.3 g or 13 mN at 37°C in a Krebs solution (pH 7.5) containing (in mM): NaCl (117.50), KCl (5.6), $CaCl_2.2H_2O$ (2.52), $MgSO_4.7H_2O$ (1.18), $NaH_2PO_4.H_2O$ (1.28), $NaHCO_3$ (25), D-glucose.H_2O, which was continuously gassed with 5% CO_2 and 95% O_2. To test the vasodilative effects of Ang(1-7), the aortic rings of each rat were divided in 3 groups for triplicate assessment of responses to a PE ($10^{-7.5}$ M)-induced peak contraction during each of the following treatments: control (H_2O), cumulative thioether-ring-containing Ang(1-7) (10^{-10} – 10^{-6} M) and cumulative native Ang(1-7) (10^{-10} – 10^{-6} M).

<u>Results</u>

Both natural Ang(1-7) (Fig 4, open circles) and thioether-containing-Ang(1-7), with lanthionine from position 4 to 7 (Fig 4, filled squares), cause vasodilation of phenylephrine-contracted aorta. Negative controls without peptide are represented by crosses: ×, Fig 4. The vasodilating effect of the cyclized Ang(1-7) analog is significantly stronger, about two-fold more effective in amplitude, as compared to the natural Ang(1-7).

Example 5: 4,7-cyclised Ang(1-7) antagonizes Ang(1-8)-induced contraction of the trachea smooth muscle.

This example demonstrates that cyclised Ang(1-7) prevents Ang(1-8)-induced contraction of trachea rings. Similar to natural Ang(1-7), 4,7-cyclised Ang(1-7) antagonized Ang(1-8)-induced contraction of the trachea smooth muscle.

<u>Experiment</u>

Trachea rings of normal guinea-pigs were prepared for contraction measurements in isotonic organ bath set-up. The experiment was performed at 37 °C in a Krebs solution (pH 7.4) continuously gassed with 5% CO_2 and 95% O_2. First, maximal relaxation was established using isoprenaline 10^{-7} M,

5   followed by wash-out (3 times) with Krebs solution until reaching stable tonus and then maximal contraction was determined using methacholine 10^{-4} M. After wash-out, cumulative concentrations (10^{-10} up to 10^{-6} M) of native Ang(1-8) were given in the absence or presence of either linear Ang(1-7) or 4,7-cyclised Ang(1-7). The 4,7-cyclised Ang(1-7) was obtained either biologically or

10   by sulfur extrusion as described in example 1. Cyclised peptides prepared either biologically or chemically gave very similar results. Ang(1-7) or its cyclised analog was added 20 minutes prior to the cumulative doses of Ang(1-8).

15   Results

The 4,7-cycl-Ang(1-7) analog reduced the maximal contraction of trachea smooth muscle induced by Ang(1-8) by 24%. Linear Ang(1-7) caused a similar reduction (21% reduction, not significantly different from cyclized Ang(1-7)). (Table 2, Figure 5).

20

Table 2: [Cyc$^{4-7}$]Ang(1-7) antagonizes contraction of the trachea smooth muscle induced by natural Ang(1-8).

Angiotensin	mean contraction [%]	SD	SEM	P-values with respect to Ang(1-8)
Ang(1-8)	24.21	4.58	1.53	
Ang(1-7) + Ang(1-8)	19.04	5.81	2.42	0.05
[Cyc$^{4-7}$]Ang(1-7) +	18.32	4.06	1.66	0.02

42

Ang(1-8)				

Conclusion

Introduction of a thioether ring between position 4 and 7 to stabilize Ang(1-7)

5 yields a biologically active peptide analog which is an attractive analog for
therapeutic purposes, for example for treatment of pulmonary diseases or
disorders.

Example 6: Thioether-ring-containing Ang(1-7) is more effective in

10 **lowering blood pressure than its linear counterpart.**

In this example, we studied the effect of an intravenous bolus injection of
cyclized Ang(1-7) on MAP (mean arterial blood pressure) in the anesthetized
mouse. It demonstrates that cyclized Ang(1-7) lowers MAP more effectively

15 than the natural, linear peptide. Additionally, the recovery of MAP back to
normal is slower after cyclized Ang(1-7) administration.

Experimental

CD1 mice (35 to 40 g) remained under pentobarbital anesthesia throughout

20 the study. Left jugular vein and right carotid artery were canulated for peptide
injection and recording of the hemodynamic parameters, respectively. Five
minutes after bolus injection of 100 µl of saline or 1 µmol/L A779, 0.6 µmol/L of
either naturally occurring, linear Ang-(1-7) or 4,7-cyclized Ang-(1-7) were bolus
injected via jugular vein in 100 µl volume. All peptides were suspended in

25 saline. Blood pressure and heart rate were recorded for at least 15 minutes.

Results

As shown in figure 6A and B, an intravenous bolus injection of 0.06 nmol
Ang(1-7) induced a temporary reduction of MAP in the anesthesized mouse.

43

The cyclized Ang(1-7), with a thio-ether ring bridging aminoacids 4 and 7, appeared approximately 2 fold more effective in lowering MAP when compared to the natural peptide. Looking at the recovery time of MAP, this shows that cyclized Ang(1-7) not only has a stronger effect on the degree of MAP reduction

5   but also on the time-course of MAP reduction. After a bolus injection of cyclized Ang(1-7), MAP was back to normal after more than 3 min whereas after linear peptide injection the MAP recovery time was only 2 min. Both improved effects of the cyclized peptide can be explained by its resistance against proteolytic degradation especially against degradation by ACE.

10   However, an enhanced activity by improved receptor interaction of the conformationally constrained cyclized peptide as suggested by the aorta-contraction data (Example 4) may also play a role.

As for the linear peptide, the MAP effects of cyclized Ang(1-7) were effectively

15   prevented by A779, a *mas*-receptor antagonist composed of Ang(1-7) in which the Pro7 is replaced by D-Ala. This proves that the MAP lowering activity of cyclized Ang(1-7) is a result of *mas*-receptor agonism.

Conclusion

20   These data demonstrate that, cyclization of Ang(1-7) results in a stronger and longer lasting lowering effect on MAP, via the *mas*-receptor. These *in vivo* data indicate that the cyclized compound has therapeutic value.

44

Claims

1.   A cyclic angiotensin peptide analog consisting of from 4 to 10 amino acids, comprising a thioether-bridge linkage between the side chains of the amino acids corresponding to positions Tyr^4 and Pro^7 in naturally occurring Angiotensin.

5

2.   Analog according to claim 1, being an analog of Angiotensin I (Ang(1-10)), Angiotensin II (Ang(1-8)), Angiotensin III (Ang(2-8)), Angiotensin IV (Ang(3-8)), Ang(1-7) or Ang(1-9).
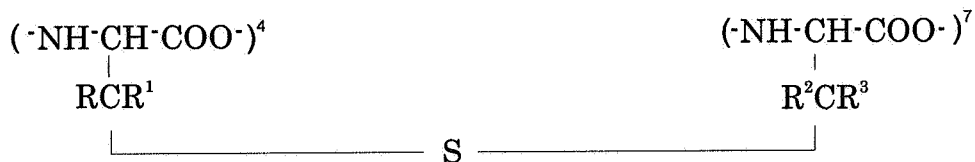
10   3.   Analog according to claim 2, being an analog of Ang(1-7).

4.   Analog according to any one of claims 1 to 3, wherein the thioether-bridge linkage between the amino acids corresponding to positions Tyr^4 and Pro^7 the general formula:

15

A)

$$(^-NH^-CH^-COO^-)^4 \qquad\qquad (^-NH^-CH^-COO^-)^7$$
$$\underset{\big|}{RCR^1} \qquad\qquad\qquad\quad \underset{\big|}{R^2CR^3}$$
$$\big\lfloor \underline{\qquad\qquad} S \underline{\qquad\qquad} \big\rfloor$$

45

B)

$$(^-NH^-CH^-COO^-)^4$$
$$|$$
$$RCR^1$$
$$|$$
$$R^2CR^3$$

$$(^-NH^-CH^-COO^-)^7$$
$$|$$
$$R^4CR^5$$

$$\underline{\hspace{3cm}} S \underline{\hspace{3cm}}$$

5

or

C)

$$(^-NH^-CH^-COO^-)^4$$
$$|$$
$$RCR^1$$

$$(^-NH^-CH^-COO^-)^7$$
$$|$$
$$R^2CR^3$$
$$|$$
$$R^4CR^5$$

$$\underline{\hspace{3cm}} S \underline{\hspace{3cm}}$$
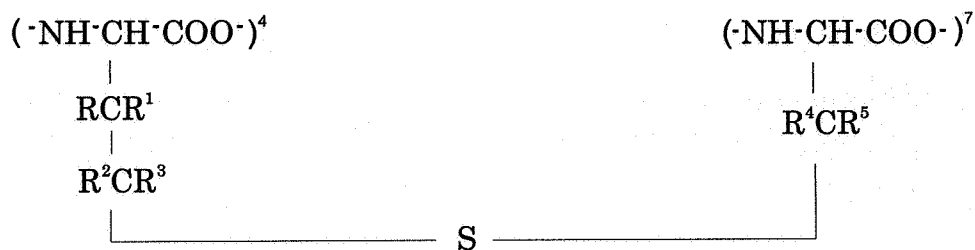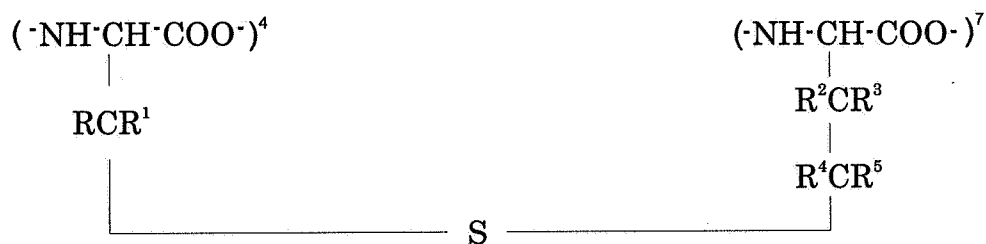
10

wherein R^1, R^2, R^3, R^4 and R^5 are independently selected from –H, a lower (e.g. C_1-C_{10}) alkyl or aralkyl group, preferably wherein R^1, R^2, R^3, R^4 and R^5 are independently selected from H and CH_3.

15

5.   Analog according to claim 4, wherein the thioether-bridge is of the formula A, preferably wherein R^1, R^2 and R^3 are independently selected from H and CH_3.

20 6.   Analog according to any one of claims 1 to 5, having the general formula Xaa^{1-10}, Xaa^{1-9}, Xaa^{1-8}, Xaa^{1-7}, Xaa^{2-7}, Xaa^{2-8} or Xaa^{3-8}, preferably Xaa^{1-7}, wherein

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Xaa¹ is any amino acid, preferably a negatively charged amino acid, more preferably Asp

Xaa² is a positively charged amino acid, preferably Arg

Xaa³ is an aliphatic amino acid, preferably Val

Xaa⁵ is an aliphatic amino acid, preferably Ile

Xaa⁶ is His

Xaa⁸ is other than Pro, preferably Phe

Xaa⁹ is other than Pro, preferably His

Xaa¹⁰ is an aliphatic amino acid, preferably Leu.

7.   Analog according to claim 6, wherein Xaa⁴ is a D-stereoisomer.

8.   Analog according to claim 6 or 7, wherein Xaa⁷ is an L- stereoisomer.

9.   Analog according to any one of claims 6 to 8, wherein Xaa¹ is Asp, Xaa² is Arg, Xaa³ is Val, Xaa⁵ is Ile, Xaa⁶ is His, Xaa⁸ is Phe, Xaa⁹ is His, Xaa¹⁰ is Leu.

10.   Analog according to any one of the preceding claims, selected from the group consisting of:

Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Phe-His-Leu ([Cyc⁴⁻⁷]Ang(1-10))

Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Phe-His ([Cyc⁴⁻⁷]Ang(1-9))

Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala-Ile([Cyc⁴⁻⁷]Ang(1-8)F8I),

Arg-Val-Abu/Ala-Ile-His-Abu/Ala([Cyc⁴⁻⁷]Ang(2-7)), and

Asp-Arg-Val-Abu/Ala-Ile-His-Abu/Ala([Cyc⁴⁻⁷]Ang(1-7))

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under the provision that the peptide does not contain two Abu (2-aminobutyric acid) residues.

5   11.   Pharmaceutical composition comprising a cyclic angiotensin analog according to any one of claims 1 to 10, or a pharmaceutically acceptable salt or complexes thereof, and a pharmaceutically acceptable carrier.

12.   An implantable medical device, preferably a vascular stent, provided

10   with a cyclic angiotensin analog according to any one of claims 1 to 10 having Ang(1-7) receptor agonistic activity, or a pharmaceutically acceptable salt or complexes thereof.

13.   Method for the treatment or prophylaxis of a disease or disorder

15   involving unwanted vasoconstriction, comprising administering to a subject in need thereof a therapeutically effective dose of a cyclic angiotensin analog according to any one of claims 1 to 10 having Ang(1-8) receptor antagonistic activity and/or Ang(1-7) receptor agonistic activity, or a pharmaceutically acceptable salt or complexes thereof.

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14.   Method for the treatment or prophylaxis of a disease or disorder involving unwanted trachea constriction, comprising administering to a subject in need thereof a therapeutically effective dose of a cyclic angiotensin analog according to any one of claims 1 to 10 having Ang(1-8) receptor

25   antagonistic activity and/ or Ang(1-7) receptor agonistic activity, or a pharmaceutically acceptable salt or complexes thereof.

15.   Method for the treatment of cancer, comprising administering to a subject in need thereof a therapeutically effective dose of a cyclic angiotensin

30   analog according to any one of claims 1 to 10 having Ang(1-8) receptor

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antagonistic activity and/or Ang(1-7) receptor agonistic activity, or a
pharmaceutically acceptable salt or complexes thereof.

16.   Method for accelerating tissue repair, comprising administering to a
5   subject in need thereof a therapeutically effective dose of a cyclic angiotensin
analog according to any one of claims 1 to 10 having Ang(1-7) receptor
agonistic activity, or a pharmaceutically acceptable salt or complexes thereof.

17.   Use of a cyclic angiotensin analog according to any one of claims 1 to
10   10 having Ang(1-8) receptor antagonistic activity and/or Ang(1-7) receptor
agonistic activity, or a pharmaceutically acceptable salt or complexes thereof,
for the manufacture of a medicament for the treatment of the treatment or
prophylaxis of a disease or disorder involving unwanted vasoconstriction,
preferably a renal or cardiovascular disease involving unwanted
15   vasoconstriction, such as hypertension, heart failure or diabetes-induced
cardiovascular dysfunction.

18.   Use of a cyclic angiotensin analog according to any one of claims 1 to
10 having Ang(1-8) receptor antagonistic activity or Ang(1-7) receptor agonistic
20   activity, or a pharmaceutically acceptable salt or complexes thereof, for the
manufacture of a medicament for the treatment or prophylaxis of a disease or
disorder involving unwanted trachea constriction, preferably wherein said
disease or disorder is airway hyperresponsiveness, airway remodelling or other
pulmonary obstruction related -disease, such as asthma, COPD or chronic
25   pulmonary obstructive disease.

19.   Use of a cyclic angiotensin analog according to any one of claims 1 to
10 having Ang(1-8) receptor antagonistic activity or Ang(1-7) receptor agonistic
activity, or a pharmaceutically acceptable salt or complexes thereof, for the

manufacture of a medicament for the treatment of cancer, preferably breast
cancer, lung cancer, or adenocarcinoma.

20.   Use of a cyclic angiotensin analog according to any one of claims 1 to
5   10 having Ang(1-7) receptor agonistic activity, or a pharmaceutically
acceptable salt or complexes thereof, for the manufacture of a medicament for
the treatment of increase the healing rate of tissue

21.   Method according to any one of claims 12 to 16, or use according to
10   any one of claims 17 to 20, wherein said angiotensin analog having Ang(1-8)
antagonistic activity or Ang(1-7) agonistic activity is [Cyc$^{4-7}$]Ang(1-7),
preferably having the amino acid sequence Asp-Arg-Val-Abu/Ala-Ile-His-
Abu/Ala.

Figure 1A
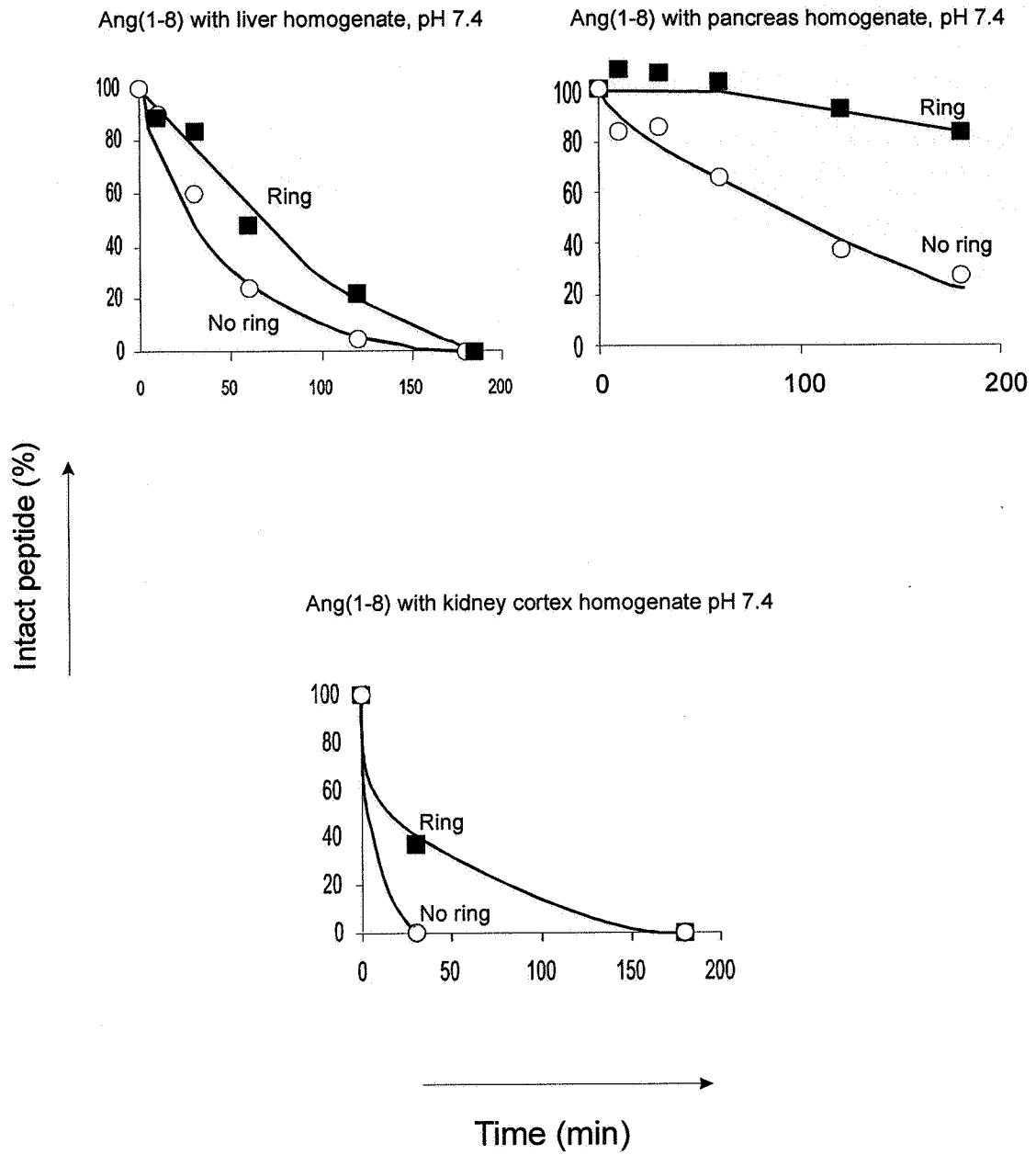
Figure 1B

Angiotensin (1-7)
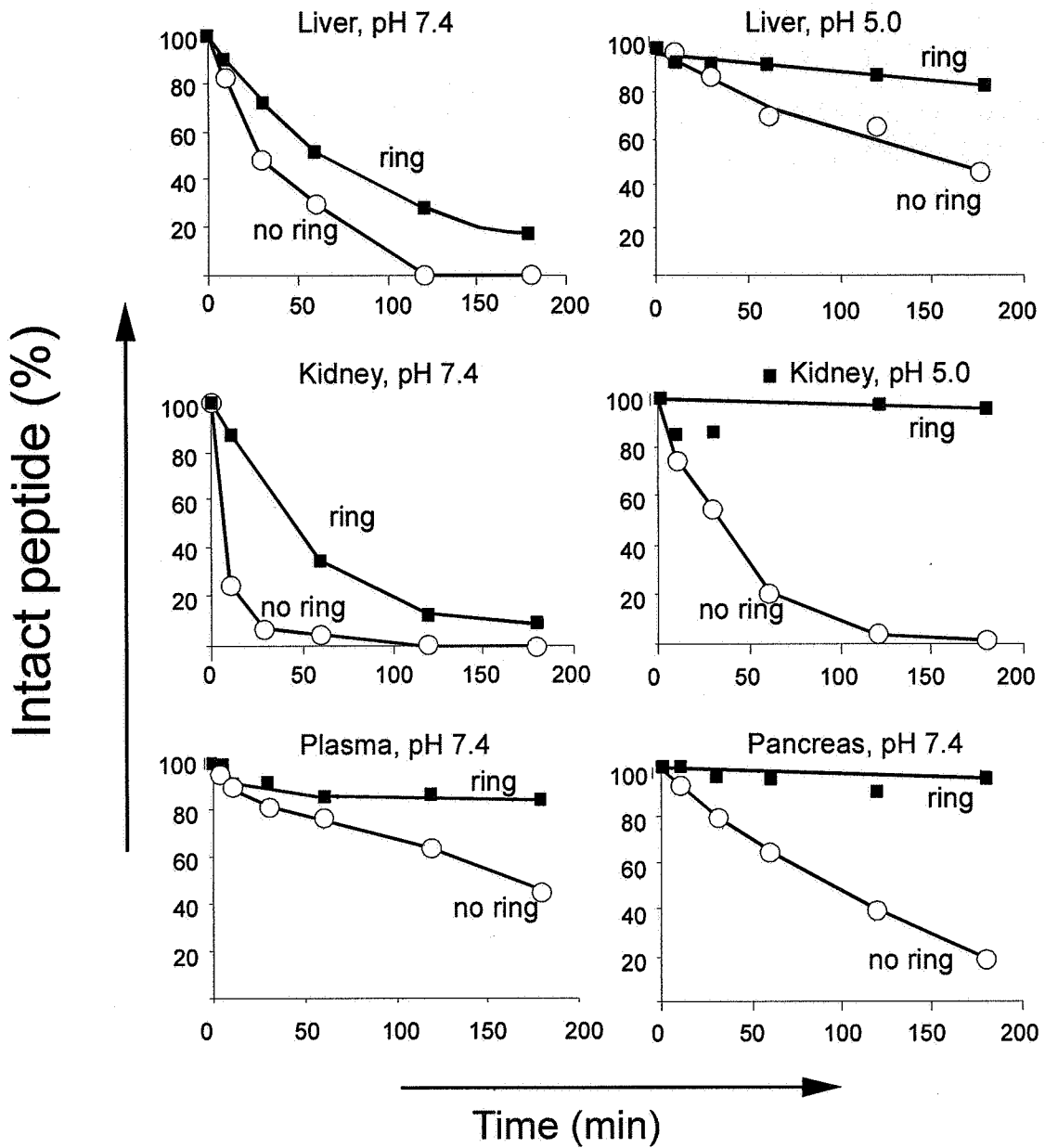
Figure 2A
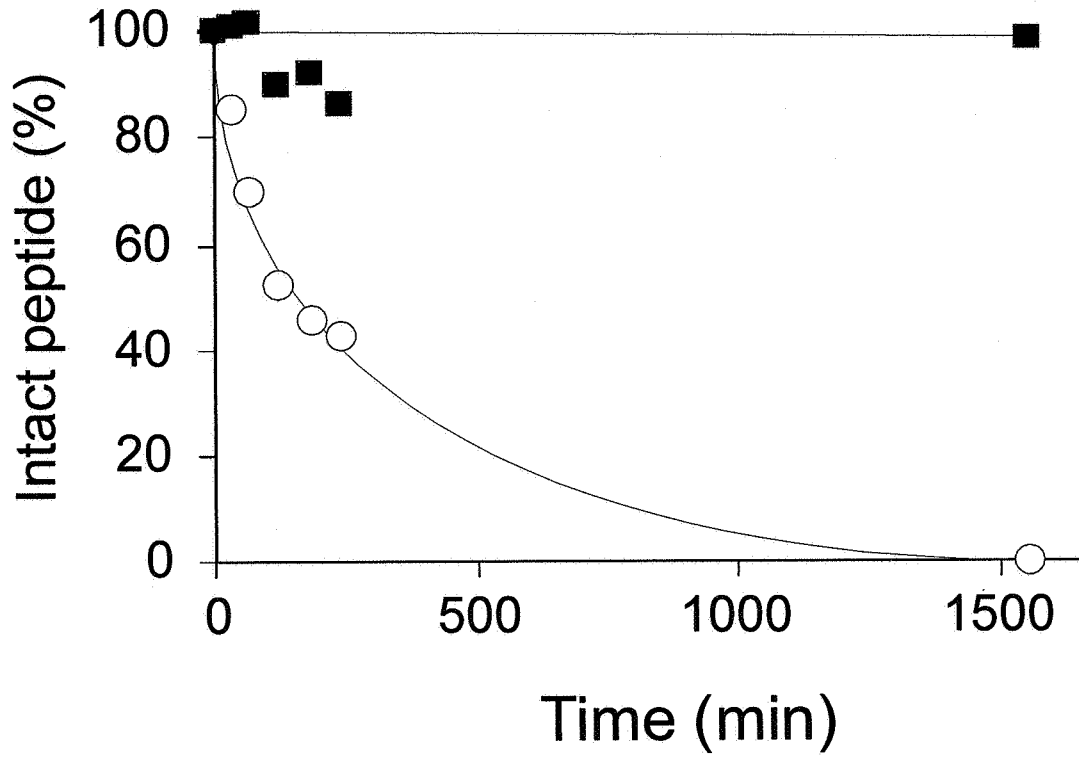
Figure 2B
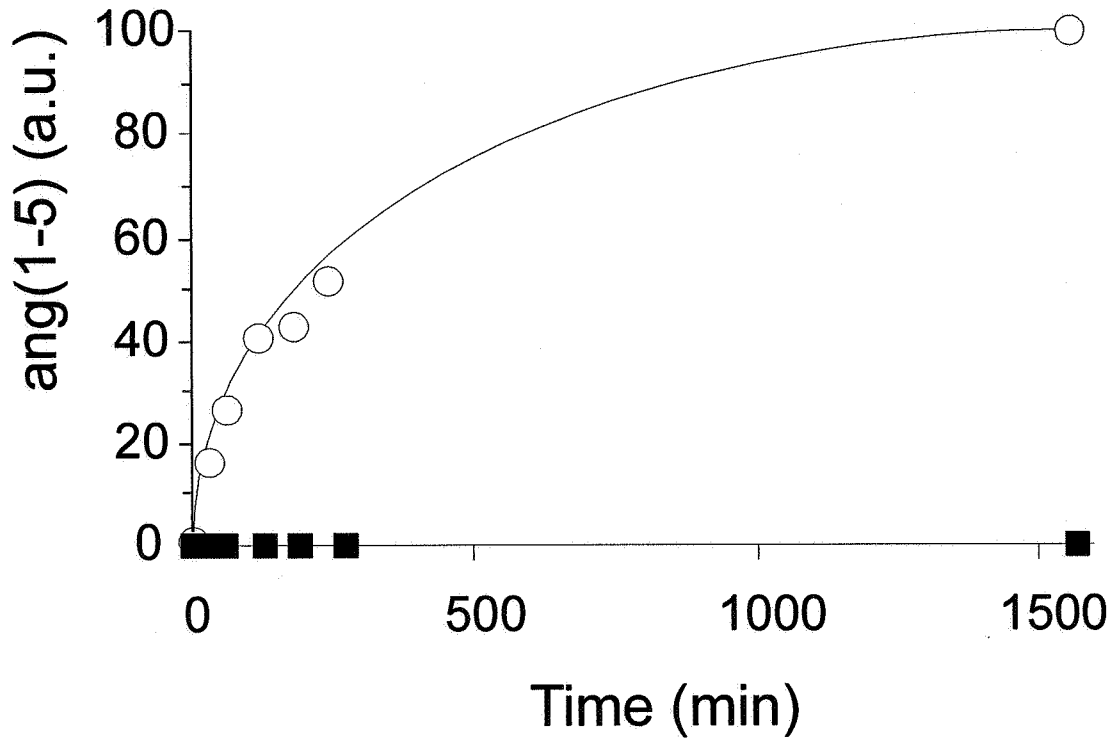
Figure 2C
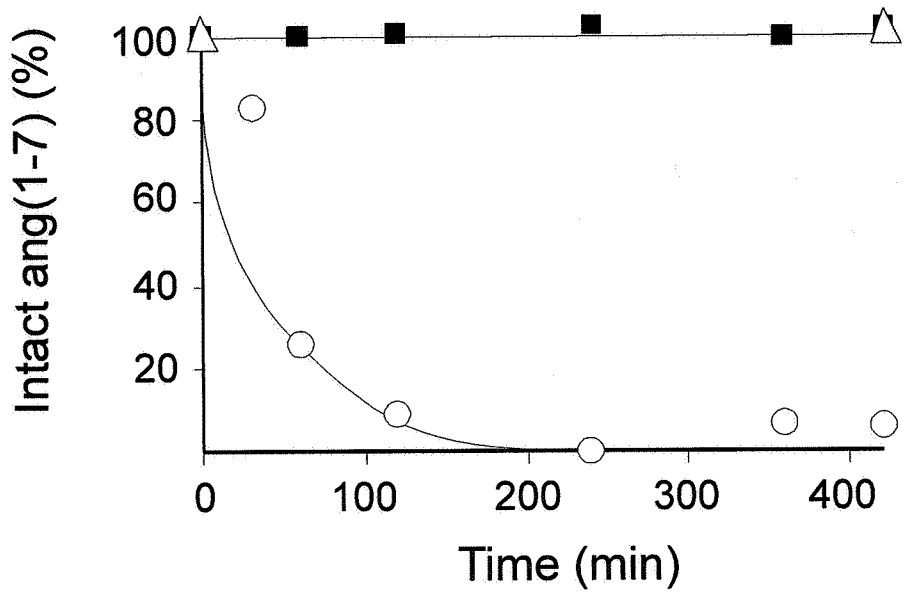
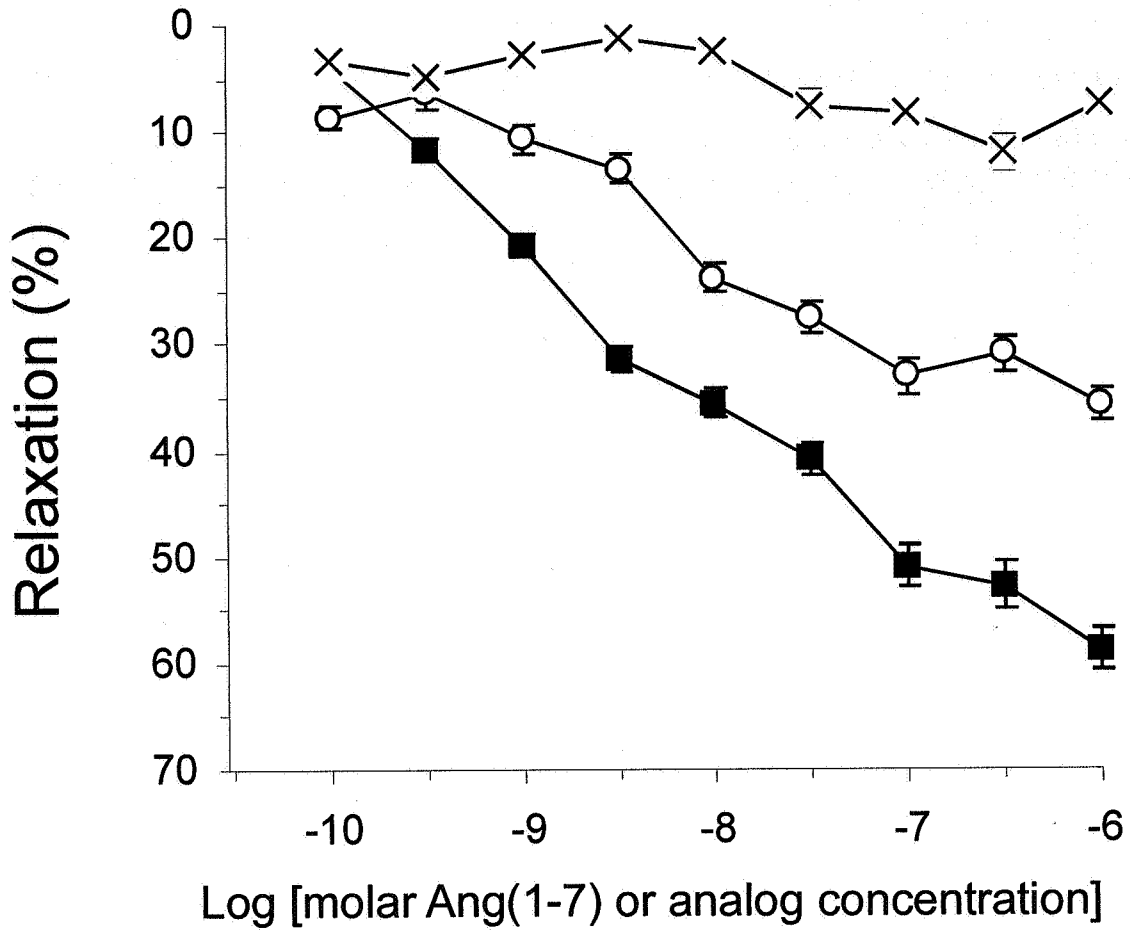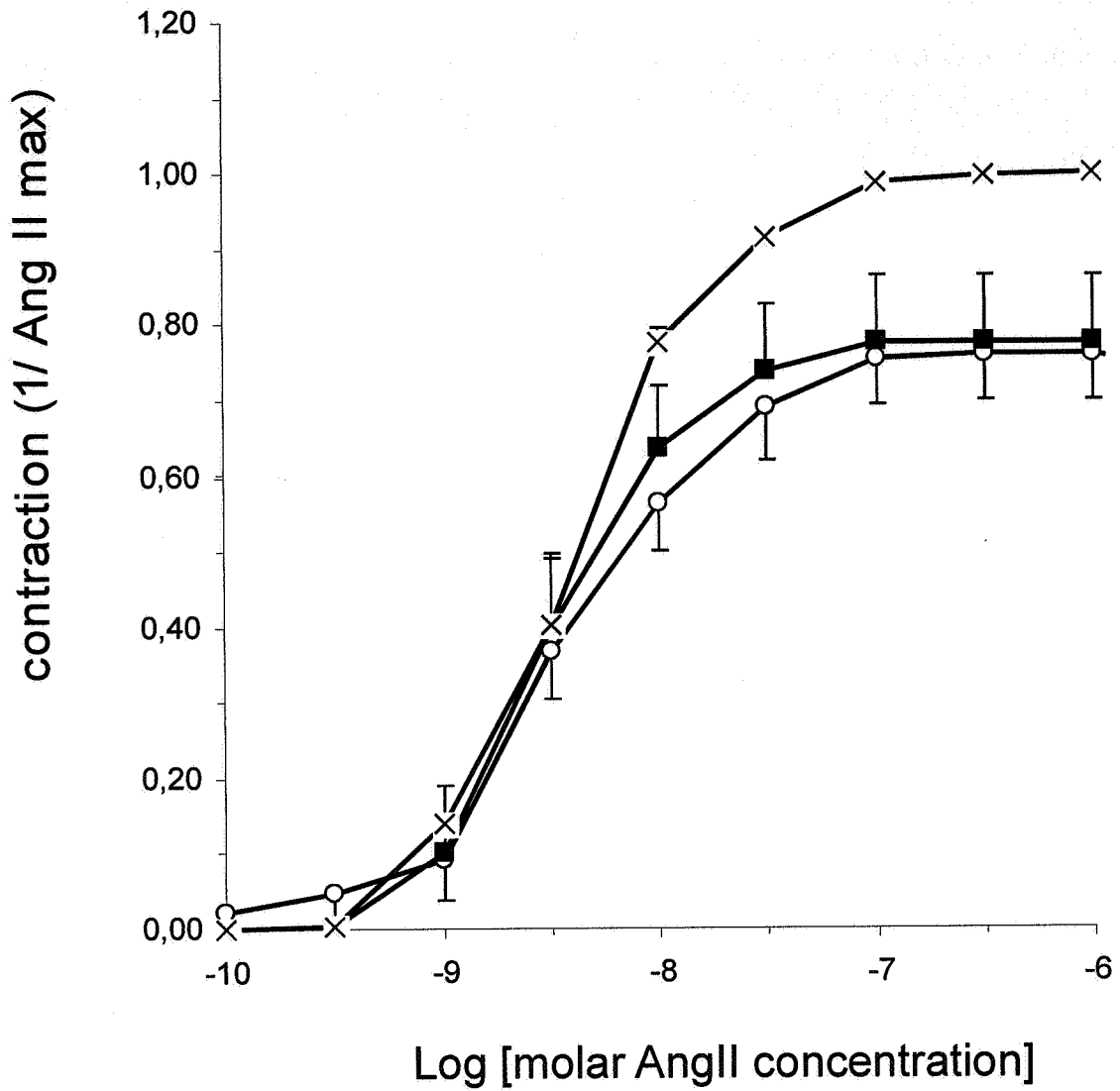Figure 2D

Figure 3

Figure 4

Log [molar Ang(1-7) or analog concentration]
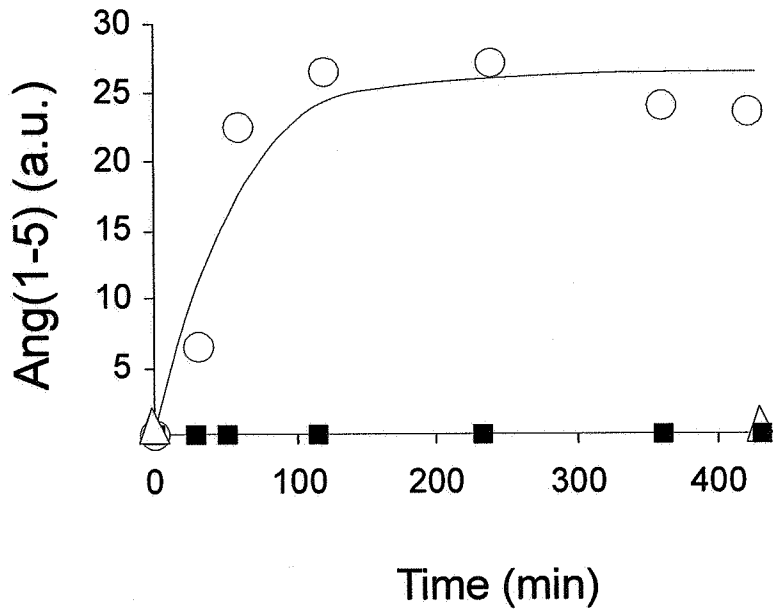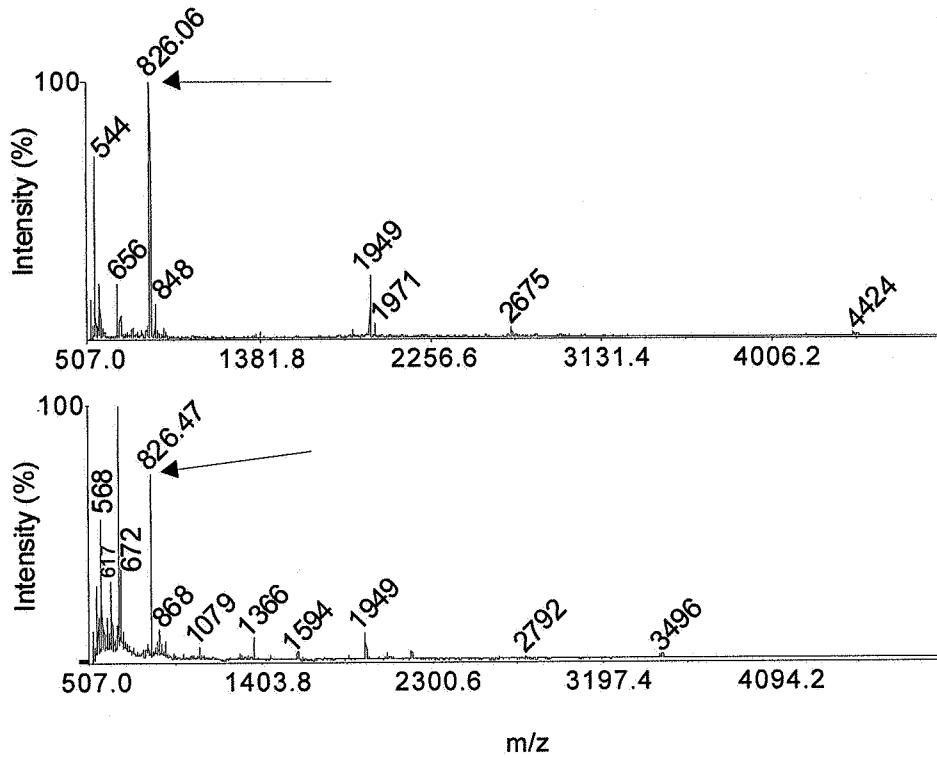
Figure 5

Figure 6A

Figure 6B

Figure 7