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(54) Titre : TRAITEMENT DE L'AMYLOIDOSE ASSOCIEE A LA MALADIE D'ALZHEIMER

(54) Title: TREATMENT OF AMYLOIDOSIS ASSOCIATED WITH ALZHEIMER'S DISEASE

(57) **Abrégé/Abstract:**

A method of regulating protein phosphorylation of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques comprising introducing an effective amount of a kinase modulator or phosphatase modulator, the modulator capable of increasing or decreasing the rate of proteolytic processing of the proteins.



A method of regulating protein phosphorylation of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques comprising introducing an effective amount of a kinase modulator or phosphatase modulator, the modulator capable of increasing or decreasing the rate of proteolytic processing of the proteins.

BACKGROUND OF THE INVENTIONField of the Invention

The present invention concerns a method for the treatment of amyloidosis associated with Alzheimer's disease by administering to a patient an effective amount of at least one agent that modulates or effects the phosphorylation of proteins in mammalian cells.

Background Information

Alzheimer's disease (AD) is a brain disorder characterized by abnormal protein phosphorylation and altered protein catabolism. From the work of several laboratories, altered protein phosphorylation has been implicated in the formation of the intracellular neurofibrillary tangled found in Alzheimer's disease. However, a role for protein phosphorylation in the catabolism of the β /A4 protein precursor (β APP) has not been demonstrated.

Alzheimer's disease is the most common single cause of dementia in late life. Individuals with Alzheimer's disease are characterized by progressive memory impairments, loss of language and visuospatial skills and behavior deficits. The cognitive impairment of individuals with Alzheimer's disease is the result of degeneration of neuronal cells located in the cerebral cortex, hippocampus, basal forebrain and other brain regions. Histologic analyses of Alzheimer's disease

brains obtained at autopsy demonstrated the presence of neurofibrillary tangles (NFT) in perikarya and axons of degenerating neurons, extracellular neuritic (senile) plaques, and amyloid plaques inside and around some blood vessels of affected brain regions. Neuritic plaques are located at degenerating nerve terminals (both axonal and dendritic), and contain a core compound of amyloid protein fibers. Cerebrovascular amyloid protein material is found in blood vessels in the meninges and the cerebral cortex (Glenner and Wong, 1984, Biochem. Biophys. Res Commun., 120:885-890; Glenner and Wong, 1984, Biochem. Biophys. Res. Commun., 122:1131-1135; Wong et al, 1985, Proc. Natl. Acad. Sci., U.S.A., 82:8729-8732).

A central feature of the pathology of Alzheimer's disease is the deposition of amyloid protein within plaques. The 4 kDa amyloid protein (also referred to as A4 (APC, β -amyloid or BAP) is a truncated form of the larger amyloid precursor protein (APP) which is encoded by a gene localized on chromosome 21 (Goldgaber et al, 1987, Science, 235:877-880; Kang et al, 1987, Nature, 325:733-736; Jenkins et al, 1988, Biochem. Biophys. Res. Commun., 151:1-8; Tanzi et al, 1987, Science, 235:880-885).

In summary, Alzheimer's disease is characterized by certain neuropathological features including intracellular neurofibrillary tangles, primarily composed of cytoskeletal proteins, and

extracellular parenchymal and cerebrovascular amyloid (Katzman, R., Biological Aspects of Alzheimer's Disease, Cold Spring Harbor, New York). Biochemically, Alzheimer's disease is characterized by changes in protein phosphorylation. Two components of neurofibrillary tangles, namely the microtubule-associated protein tau and neurofilament proteins found in the neurofibrillary tangles are abnormally phosphorylated (perhaps by calcium/calmodulin-dependent protein kinase II (CaMKII)) (Sternberger, N.H., Sternberger, L.A. and Ulrich, J., (1985), Proc. Natl. Acad. Sci., U.S.A., 82:4274 and Flament, S. and Delacourte, A., (1989), FEBS Lett., 247:213). Protein kinase C (PKC) activity is reported to be reduced in Alzheimer's disease brain as well as in fibroblasts from Alzheimer's disease, familial Alzheimer's disease and Down's syndrome patients (Cole, G., Dobkins, K.R., Hausen, L.A., Terry, R.D. and Saitoh, T., (1988), Brain Res., 452:165-174 and Huyhn, T.V., Cole, G., Katzman, R., Haung, R.-P. and Saitoh, T. (1989), Arch. Neurol., 46:1195-1199). A cytosolic 60 kDa phosphoprotein is reported to be present at two-fold higher concentration in Alzheimer's disease brain when compared to controls (Saitoh, T. and Dobkins, K.R. (1986), Proc. Natl. Acad. Sci., 83:9764-9767).

The major constituent of cerebral plaques and cerebrovascular amyloid, the β /A4 protein, is derived from a large transmembrane protein, β /A4 amyloid

precursor protein, or β APP. β APP is comprised of three major isoforms, β APP₆₉₅, β APP₇₅₁ and β APP₇₇₀, which arise from alternate splicing and are denoted by the lengths of their primary sequences. This protein is a phosphoprotein, and it has previously been proposed that the altered phosphorylation associated with Alzheimer's disease might affect not only tangle proteins, but might also alter the metabolism of β APP, perhaps leading to deposition of β A4 (Gandy et al, (1988), Proc. Natl. Acad. Sci., U.S.A. 85:6218).

Using a synthetic peptide corresponding to a potential phosphorylation site in the β App transmembrane and cytoplasmic domain, it has previously been shown that this peptide is a highly efficient substrate for PKC or CaM K II. The putative PKC phosphorylation site of β APP, located seven residues from the predicted transmembrane/cytoplasmic border of the protein, is similar to a PKC-Phosphorylation site found in both the epidermal growth factor receptor and in the interleukin-2 receptor. Phosphorylation of either of these two receptors by PKC at these sites targets them for internalization. By analogy, phosphorylation of β APP may regulate its internalization and catabolism.

SUMMARY OF THE INVENTION

Applicants have extended the above observations by studying the effects of agents that regulate protein

phosphorylation on the metabolism of β APP, using PC12 rat pheochromocytoma cells as a model system. The metabolism of β APP in PC12 has been well characterized (Wiedemann, A., Konig, G., Buke, D., Fischer, Pl., Salbaum, J.M., Masters, C.L. and Beyreuther, K. (1989), Cell, 57:115) making this cell line particularly useful. Applicants observed that β APP metabolism is regulated by agents that regulate protein phosphorylation and it is believed that alterations in protein phosphorylation will modify the deposition of β /A4 in extracellular sites characteristic of Alzheimer's disease.

The present invention concerns a method of regulating protein phosphorylation of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques comprising introducing, e.g., introducing into a patient or into a cell of a patient, an effective amount of a kinase modulator or a phosphatase modulator, the modulator being capable of increasing or decreasing the rate of proteolytic processing of such proteins.

The invention also relates to the use of the kinase modulator or phosphatase modulator in the manufacture of a medicament for such method.

The present invention is also directed to a method of inhibiting production of Alzheimer type amyloidosis in a mammal comprising administering to the mammal an effective amount of at least one inhibitor of protein phosphatase, the inhibitor being capable of decreasing the proteolytic processing of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques.

The invention also relates to the use of such inhibitor in the manufacture of a medicament for such method.

The present invention also relates to a treatment of amyloidosis associated with Alzheimer's disease in a mammalian patient comprising administering to the patient an effective amount of at least one agent capable of modulating the phosphorylation of proteins in mammalian cells.

The invention also relates to the use of such agent in the manufacture of a medicament for such method.

In accordance with another aspect of the invention there is provided a pharmaceutical composition for regulating phosphorylation of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques comprising an effective amount of a kinase modulator or a phosphatase modulator, said modulator being capable of increasing or decreasing the rate of proteolytic processing of said proteins, in association with a pharmaceutically acceptable carrier.

In accordance with still another aspect of the invention there is provided a pharmaceutical composition for inhibiting production of Alzheimer type amyloidosis in a mammal comprising an effective amount of at least one inhibitor of protein phosphatase, said inhibitor being capable of decreasing the proteolytic processing of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques, in association with a pharmaceutically acceptable carrier.

In accordance with yet another aspect of the invention there is provided a pharmaceutical composition for treating amyloidosis associated with Alzheimer's disease in a mammalian patient comprising an effective amount of at least one agent capable of modulating the phosphorylation of proteins in mammalian cells, in association with a pharmaceutically acceptable carrier.

The present invention also relates to a method for screening for agents that modulate amyloid formation comprising contacting mammalian cells with an agent suspected of being capable of modulating the phosphorylation proteins and detecting for alterations in the degradation of the amyloid precursor protein.

The present invention also is directed to a method for screening for agents that modulate amyloid formation in a normal or transgenic whole animal comprising administering to said animal an agent suspected of being capable of modulating phosphorylation of proteins and detecting neurodegenerative changes in the brain of the animal.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 are autoradiographs of PAGE gels from immunoprecipitates of [³⁵S]methionine labeled PC12 cells.

Fig. 2 are three graphs showing the effect of agents that modulate PKC activity on β APP proteins in PC12 cells.

Fig. 3 are three graphs showing the effect of PDBu on motive β APP proteins.

Fig. 4 are three graphs showing the regulation of β APP processing by okadaic acid as a function of time.

Fig. 5 are three graphs showing the regulation by okadaic acid of processing mature β APP as a function of time.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1. Regulation of β APP processing by PDBu and okadaic acid

(A) Identification of β APP and β APP -derived peptides in PC12 cells by immunoprecipitation with anti- β APP⁶⁴⁵⁻⁶⁹⁴ antibodies. Autoradiographs of PAGE gels from immunoprecipitates of [³⁵S]methionine labeled PC12 cells are shown. In the upper panel an autoradiograph of the higher molecular weight region of a 6-18% gradient gel is shown. In the lower panel an autoradiograph of a longer exposure of the lower molecular weight of the gel including the 15 kDa and 19 kDa peptides is shown.

(B) Lanes: 1, Immunoprecipitate of labeled PC12 cells under control conditions at zero-time; 2-6.

Immunoprecipitates of labeled PC12 cells at 45 minutes of chase with additions at zero time; 2, Control cells; 3, Cells treated with $1\mu\text{M}$ PDBu; 4, Cells treated with $1\mu\text{M}$ okadaic acid; 5, Cells treated with $1\mu\text{M}$ PDBu and $1\mu\text{M}$ okadaic acid; 6, Cells treated with $1\mu\text{M}$ PDBu and $1\mu\text{M}$ okadaic acid immunoprecipitated in the presence of $100\text{ }\mu\text{M}$ $\beta\text{APP}^{645-694}$ peptide. The putative βAPP forms in PC12 cells are related to human βAPP_{695} as determined by limited proteolysis. The 113/115 kDa doublet (lane 1) and the 143/149 kDa doublet (lane 2) were excised from the gel shown in A and subjected to limited proteolysis digestion with V8 protease and compared with similarly treated in vitro transcribed and translated human βAPP_{695} cDNA (lane 3).

Figure 2. Regulation of βAPP processing by PDBu and H-7 as a function of time

PC12 cells were metabolically labeled for 20 minutes with [^{35}S] methionine followed by a chase period with complete medium for the indicated times. Agents regulating PKC activity were added at the start of the chase period (zero-time). Following cell lysis, extracts were subjected to immunoprecipitation, NaDodSO₄-PAGE and autoradiography. The various forms of βAPP were quantified by scanning the

autoradiogram. The results shown are the means $\pm$ SEM of four experiments. The data were normalized such that the total $\beta\text{APP}_{751/770}$ recovered (i.e., immature and mature) at zero-time was taken as 100 units. The levels of the COOH-terminal βAPP fragments were insignificant at zero-time. In A and B, recovery is expressed at percent of total at zero-time. In C, recovery is expressed as arbitrary units.

(A) Immature $\beta\text{APP}_{751/770}$. (B) Mature $\beta\text{APP}_{751/770}$. (C) 15 kDa COOH-terminal fragment. Control cells ($\bullet$), PDBu-treated cells (), H-7-treated cells ().

Figure 3. Regulation by PDBu of processing of mature βAPP as a function of time

PDBu was added at 35 minutes of chase to allow the mature βAPP to approach maximal levels. All other experimental details were as described in the legend to Fig. 2. The experiment shown is representative of three separate experiments. Experimental points are the means of duplicate determination.

(A) Immature $\beta\text{APP}_{751/770}$. (B) Mature $\beta\text{APP}_{751/770}$. (C) 15 kDa COOH-terminal fragment. Control cells ($\bullet$), PDBU-treated cells ().

Figure 4. Regulation of β APP processing by okadaic acid as a function of time

Okadaic acid ($1\ \mu\text{M}$) was added directly at the start of the chase (zero-time). All other experimental details were as described in the legend to Fig. 2. The results shown are the mean $\pm$ SEM of 4 experiments.

(A) Immature $\beta\text{APP}_{751/770}$. (B) Mature $\beta\text{APP}_{751/770}$. (C) 15 kDa COOH-terminal fragment. Control cells ($\bullet$), okadaic acid-treated cells ($\circ$).

Figure 5. Regulation by okadaic acid of processing mature β APP as a function of time

Okadaic acid ($1\ \mu\text{M}$) was added at 35 minutes of chase to allow the mature β APP to approach maximal levels. All other experimental details were as described in the legend to Fig. 2. The experiment shown is representative of two separate experiments. Experimental points are the means of duplicate determination.

(A) Immature $\beta\text{APP}_{751/770}$. (B) Mature $\beta\text{APP}_{751/770}$. (C) 15 kDa COOH-terminal fragment. Control cells ($\bullet$), okadaic acid-treated cells ($\circ$).

DETAILED DESCRIPTION OF THE INVENTION

As reported (Wiedemann et al, supra), β APP in PC12 cells matures over 45 minutes and is probably processed via

a lysosomal pathway. Phorbol esters lead to an apparent stimulation in the rate of this processing. This suggests that protease kinase C (PKC) may target β APP for internalization and degradation, analogous to its effects in regulating the trafficking of the epidermal growth factor and interleukin-2 receptors. The fact that H7, an inhibitor of PKC, leads to an apparent decrease in the basal rate of processing of β APP suggests that in the unstimulated cell β APP may be cleaved after it is phosphorylated by basally active PKC.

The effect of activators of PKC on the levels of the 15kDa and 19 KDa β APP fragments has been examined in view of the known normal processing of β APP. It has been reported that the extracellular portion of β APP is normally secreted after β APP is cleaved within the B/A4 domain. This means that normal β APP processing precludes amyloidogenesis and, presumably, cerebral plaque formation. The 15 kDa and 19 kDa C-terminal β APP fragments have molecular weights consistent with their possibly containing the entire B/A4 sequence and therefore potentially being amyloidgenic.

The fact that BayK was without effect on β APP suggests that CaMKII is not involved in β APP catabolism in applicants' assay system. The effects of inonomycin is believed to be due to effects of this inonophore on calcium gradients across the Golgi membrane.

Okadaic acid, as a potent inhibitor of phosphatases 1 and 2A, increases net phosphorylation for many substrates of numerous protein kinases. Therefore, the effect of okadaic acid on BAPP processing cannot be attributed to any one kinase and is believed to involve phosphorylation of BAPP by kinases distinct from those characterized previously, or phosphorylation of other proteins involved in the regulation of BAPP maturation and processing.

The effects of PDBu and okadaic acid on the 15 and 19 kDa fragments is believed to arise from phosphorylation causing either a more rapid breakdown of the mature BAPP or a slowing down of the catabolism of the 15 and 19 kDa fragments. There is a possibility that the 19 kDa fragment is a phosphorylated form of the 15 kDa fragment.

The following is a list of compounds ("active compounds") which affect or modulate the phosphorylation state of proteins in mammalian cells. Phosphorylation state can be modulated by inhibiting or stimulating the activity of kinases which add a phosphate moiety to proteins, or by inhibiting or stimulating phosphatases which remove a phosphate moiety from proteins.

The following is not meant to be a complete or exhaustive list, but a list of well known examples:

Kinase stimulators:

Phorbol esters - e.g., 4-alpha-phorbol 12,13-dibutyrate, phorbol 12-myristate 13-acetate (PMA) or (phorbol-12,13-dibutyrate (PDBU or PDBu)

Indolactams - e.g., (-)-7-octylindolactam V

Mezerin

Diacylglycerol

Forskolin

3-(N-acetylamino)-5-(N-decyl-N-methylamino)-benzyl alcohol (ADMB) and

6-(N-decylamino)-4-hydroxymethylindole (DHI)

Kinase inhibitors:

Staurosporine

Auranofin

W5, W12, W13, W7, H7, H8, H9 or HA1004 (W7 is N-(6-aminohexyl)-5-chloro-1-naphthanesulfamide hydrochloride; H7 is 1-(5-isoquinolinesulfonyl)-2-methylpiperazine dihydrochloride; H8 is N-[2-(methylamino)ethyl]-3-isoquinolinesulfonamide dihydrochloride; H9 is N-(2-aminoethyl)-5-isoquinolinesulfonamide; HA1004 is N(2-guanidinoethyl)-5-isoquinoline-sulfonamide hydrochloride; W5 is N-(6-aminohexyl)-1-naphthalenesulfonamide hydrochloride; W12 is N-(4-aminobutyl)-2-naphthalenesulfonamide hydrochloride and W13 is N-(-4-aminobutyl)-5-chloro-2-naphthalenesulfonamide hydrochloride)

Sphingosine

Tyrphostin

Phosphatase inhibitors:

Okadaic acid and derivatives thereof

Calyculin-A

Vanadate

Phosphatase stimulators:

Somatostatin analogs.

It is to be understood that derivatives of the above stimulators and inhibitors are encompassed by the present invention.

The active compounds for use in the present invention can be administered as a medicament, i.e., a pharmaceutical composition.

The pharmaceutical compositions used in the methods of this invention for administration to animals and humans comprise an active compound in association with a pharmaceutical carrier or excipient.

The medicament can be in the form of tablets (including lozenges and granules), dragees, capsules, pills, ampoules or suppositories comprising the compound of the invention.

"Medicament" as used herein means physically discrete coherent portions suitable for medical administration. "Medicament in dosage unit form" as used herein means physically discrete coherent units suitable for medical administration, each containing a daily dose or a multiple (up to four times) or a sub-multiple (down to a

fortieth) of a daily dose of the active compound of the invention in association with a carrier and/or enclosed within an envelope. Whether the medicament contains a daily dose, or for example, a half, a third or a quarter of a daily dose will depend on whether the medicament is to be administered once or, for example, twice three times or four times a day, respectively.

Advantageously, the compositions are formulated as dosage units, each unit being adapted to supply a fixed dose of active ingredients. Tablets, coated tablets, capsules, ampoules and suppositories are examples of preferred dosage forms according to the invention. It is only necessary that the active ingredient constitute an effective amount, i.e., such that a suitable effective dosage will be consistent with the dosage form employed in single or multiple unit doses. The exact individual dosages, as well as daily dosages, will of course be determined according to standard medical principles under the direction of a physician or veterinarian.

The active compound can also be administered as suspensions, solutions and emulsions of the active compound in aqueous or non-aqueous diluents, syrups, granulates or powders.

Diluents that can be used in pharmaceutical compositions (e.g., granulates) containing the active compound adapted to be formed into tablets, dragees,

capsules and pills include the following: (a) fillers and extenders, e.g., starch, sugars, mannitol and silicic acid; (b) binding agents, e.g., carboxymethyl cellulose and other cellulose derivatives, alginates, gelatine and polyvinyl pyrrolidone; (c) moisturizing agents, e.g., glycerol; (d) disintegrating agents, e.g., agar-agar, calcium carbonate and sodium bicarbonate; (e) agents for retarding dissolution, e.g., paraffin; (f) resorption accelerators, e.g., quaternary ammonium compounds; (g) surface active agents, e.g., cetyl alcohol, glycerol monostearate; (h) adsorptive carriers, e.g., kaolin and bentonite; (i) lubricants, e.g., talc, calcium and magnesium stearate and solid polyethyl glycols.

The tablets, dragees, capsules and pills comprising the active compound can have the customary coatings, envelopes and protective matrices, which may contain opacifiers. They can be so constituted that they release the active ingredient only or preferably in a particular part of the intestinal tract, possibly over a period of time. The coatings, envelopes and protective matrices may be made, for example, from polymeric substances or waxes.

The active ingredient can also be made up in microencapsulated form together, with one or several of the above-mentioned diluents.

The diluents to be used in pharmaceutical compositions adapted to be formed into suppositories can, for example, be the usual water-soluble diluents, such as polyethylene glycols and fats (e.g., cocoa oil and high esters, [e.g., C₁₄-alcohol with C₁₆-fatty acid]) or mixtures of these diluents.

The pharmaceutical compositions which are solutions and emulsions can, for example, contain the customary diluents (with, of course, the above-mentioned exclusion of solvents having a molecular weight below 200, except in the presence of a surface-active agent), such as solvents, dissolving agents and emulsifiers. Specific non-limiting examples of such diluents are water, ethyl alcohol, isopropyl alcohol, ethyl carbonate, ethyl acetate, benzyl alcohol, benzyl benzoate, propylene glycol, 1,3-butylene glycol, dimethylformamide, oils (for example, ground nut oil), glycerol, tetrahydrofurfuryl alcohol, polyethylene glycols and fatty acid esters of sorbitol or mixtures thereof.

For parenteral administration, solutions and emulsions should be sterile, e.g., water or arachis oil contained in ampoules and, if appropriate, blood-isotonic.

The pharmaceutical compositions which are suspensions can contain the usual diluents, such as liquid diluents, e.g., water, ethyl alcohol, propylene glycol, surface-active agents (e.g., ethoxylated isostearyl

alcohols, polyoxyethylene sorbite and sorbitane esters), microcrystalline cellulose, aluminum methahydroxide, bentonite, agar-agar and tragacanth or mixtures thereof.

The pharmaceutical compositions can also contain coloring agents and preservatives, as well as perfumes and flavoring additions (e.g., peppermint oil and eucalyptus oil) and sweetening agents, (e.g., saccharin and aspartame).

The pharmaceutical compositions will generally contain from 0.5 to 90% of the active ingredient by weight of the total composition.

In addition to the active compound, the pharmaceutical compositions and medicaments can also contain other pharmaceutically active compounds.

Any diluent in the medicaments of the present invention may be any of those mentioned above in relation to the pharmaceutical compositions. Such medicaments may include solvents of molecular weight less than 200 as the sole diluent.

It is envisaged that the active compound will be administered perorally, parenterally (for example, intramuscularly, intraperitoneally, subcutaneously, transdermally or intravenously), rectally or locally, preferably orally or parenterally, especially perlingually, or intravenously.

The dosage rate, e.g., 0.05 to 20 mg/kg of body weight, will be a function of the nature and body weight of

the human or animal subject to be treated, the individual reaction of this subject to the treatment, type of formulation in which the active ingredient is administered, the mode in which the administration is carried out and the point in the progress of the disease or interval at which it is to be administered. Thus, it may in some case suffice to use less than a minimum dosage rate, while other cases an upper limit must be exceeded to achieve the desired results. Where larger amounts are administered, it may be advisable to divide these into several individual administrations over the course of the day.

EXAMPLES

Phorbol 12,13-dibutyrate (PDBu), 4-alpha-phorbol 12,13-dibutyrate (4 α PDBu) and phorbol 12-myristate 13-acetate (PMA) were purchased from LC Service Corp., Woburn, Ma. Okadaic acid was purchased from Moana BioProducts, Inc., Honolulu, HI. H7 was purchased from Seikagada Kogyo Co., Japan.

Example 1

A synthetic peptide corresponding to the cytoplasmic domain of β APP (β APP⁶⁴⁵⁻⁶⁹⁴, the numbering of amino acids corresponds to those of human β APP₆₉₅,) was prepared by the Yale Sequencing Facility. Antibodies were prepared by immunizing rabbits with this synthetic peptide

corresponding to BAPP 645-695. Sera were screened by immunoblot analysis of lysates of E.coli expressing a fusion protein including the amino acids 16-695 of human BAPP₆₉₅. Sera which were immunoreactive against the recombinant fusion protein BAPP₆₉₅ were further screened for immunoprecipitating activity in two systems: one system used ³⁵S-labeled β APP₆₉₅ which was produced by in vitro transcription of β APP₆₉₅ cDNA followed by in vitro translation of β APP₆₉₅ mRNA, using rabbit reticulocyte lysate and [³⁵S] methionine; the other system used ³⁵S-labeled β APP₆₉₅ produced by cells transfected with β APP₆₉₅ cDNA and labeled with [³⁵S] methionine. Immunoprecipitation was performed as described in Pang, D.T., Wang, J.K.T., Valtorta, F., Benfenati, F. and Greengard, P., (1988), Proc. Natl. Acad. Sci., U.S.A., 85:762-766. Sera bearing high-efficiency (>90%) immunoprecipitating activity for recombinant BAPP were affinity purified on columns of Sepharose-BAPP645-695 as described in Harlow, E. and Lane, D., Antibodies: A Laboratory Manual (Cold Spring Harbor, N.Y. 1988). The antisera used here recognized three proteins of M_r 115-140 kDa on Western blots of rat cortical homogenate, as well as a band of M_r 93 kDa.

PC cells were grown in Dulbecco's modified Eagle's medium (DMEM, Flow Labs) containing 10% (v/v) fetal calf serum and 5% heat inactivated horse serum.

For metabolic labeling of PC12 cells, the cells were washed twice, removed from the dish by trituration, and the cells were suspended at 6×10^6 cells/ml in methionine-free DMEM, supplemented with 1 mCi/ml of [^{35} S]methionine (1200 Ci/mmol, NEN Products, Boston MA.) and 20 mM Hepes, pH 7.4 for 20 minutes. The cells were then diluted with 5-6 volumes of aerated complete medium (DMEM), containing excess methionine and 20 mM Hepes, pH 7.4, and chased for time periods of 0 to 135 minutes with additions as described. Test substances were added either at the start of the chase period (zero-time) or 35 minutes later. Cell viability, as determined by trypan blue exclusion, was greater than 90% at the start of the experiment and decreased less than 5% over 135 minutes of chase.

For lysis, the cells (0.2 ml) were diluted with 0.4 ml of lysis buffer (2 mM NaN_3 , 150 mM NaCl, 100 mM Tris HCl, pH 7.4, containing 1% v/v NP40, 0.5% w/v sodium deoxycholate, 0.1% w/v NaDodSO_4 and 40 units/ml of trasylol) and placed on ice. After 20 minutes, samples were centrifuged at $10,000 \times g$ for 5 minutes, and the supernatants were used for immunoprecipitation. In some experiments, the cells were sometimes lysed with 1% NaDodSO_4 , sonicated and boiled and used for immunoprecipitation (Pang, D.T., supra). The results obtained with this procedure were virtually identical to those obtained using the standard procedure.

For immunoprecipitation, the 10,000 x g supernatant was incubated for 1 hour at 4°C with 3 μ l of undiluted or affinity-purified rabbit anti-BAPP 645-695 in a total volume of 600 μ l. Following the incubation, 75 μ l of a 1:1 suspension of Protein A-Sepharose (Pharmacia LKB, Inc., Piscataway, N.J.) in lysis buffer was then added and the incubation was continued for another 30 minutes at 4°C. The insoluble complexes were washed three times with 100 mM Tris HCl, pH 7.4, containing 150 mM NaCl and 2mM NaN₃, resuspended in solubilization buffer (62.5 mM Tris HCl, pH 6.8, 2% SDS, 5% 2-mercaptoethanol, 10% sucrose) and boiled. Proteins were separated by NaDodSO₄-PAGE and detected using quantitative fluorography with 1 M sodium salicylate. Protein bands were quantified either by densitometry of the autoradiograms, or by excising the radioactive bands and subjecting them to liquid scintillation spectrometry. BAPP₇₅₁ and BAPP₇₅₀ were the major BAPP isoforms in PC12 cells. Because these isoforms migrated very near each other on PAGE, they were quantified together and denoted BAPP_{751/770}. To quantify BAPP₆₉₅, computational methods were used (Crandell, R., McClellan, M., Arch, S., Doenias, J. and Piper, R., (1987), Anal. Biochem., 167:15). The effects observed for BAPP₆₉₅ were similar to those observed for BAPP_{751/770}. The 19 kDa peptide appeared to behave quantitatively similar to the 15 kDa peptide.

Peptide mapping of immunoprecipitated β APP or in vitro translated β APP was performed using S. aureus V8 protease (Miles Co., Elkhart, IN) according to the method of Huttner et al.

Results

PC12 cells were incubated for 20 minutes in DMEM containing [^{35} S]methionine and subsequently chased for various periods in complete medium. Immunoprecipitation from lysates of such ^{35} S-labeled cells with an antibody prepared against β APP 645-695 yielded six protein bands of 149, 143, 125, 115, 113 and 106 kDa (Fig. 1a., lanes 1 and 2).

These six proteins were not observed when the immunoprecipitation was carried out in the presence of 100 μ M β APP⁶⁴⁵⁻⁶⁹⁴ peptide (Fig. 1A, lane 6). Furthermore, these six proteins exhibited similar peptide maps when digested with V8 protease, and the maps were similar to the maps observed using in vitro transcribed and translated human β APP₆₉₅ cDNA (Fig. 1B), strongly evidencing that the immunoprecipitated protein bands are β APP isoforms.

Changes in the relative amounts of the labeled bands were observed after different durations of the chase period. A possible precursor-product relationship was noted between the doublets of M_r 113/115 and 143/149 kDa, as well as between the bands of M_r 106 and 125 kDa (Figs. 1 and 2). Based on the observations of Wiedemann et al, supra, the

proteins of M_r 143/149 and 125 kDa were tentatively identified as follows: M_r 106, 113 and 115 kDa bands, the immature (N-glycosylated) forms of β APP₆₉₅, β APP₇₅₁ and β APP₇₇₀, respectively; M_r 125, 143 and 149 kDa, the mature (N- and O- glycosylated) forms of β APP₆₉₅, β APP₇₅₁ and β APP₇₇₀, respectively. It was previously shown that a population of mature BAPP molecules is rapidly cleaved via a lysosomal mechanism, (Cole, G., Huyhn, T.V. and Saitoh, T., (1989) Neurochem. Res., 14:933) leading to secretion of the N-terminal portion. When 100 μ M chloroquine was added to PC12 cells at the beginning of the chase period, the labeled 125/143 and 149 kDa proteins were relatively increased, consistent with the action of chloroquine as an inhibitor of lysosomal acidification and cleavage of the mature BAPP forms.

Example 2: Regulation of BAPP Processing by Protein Kinase

C

When PC12 cells were incubated with 1 μ M PDBu during the chase period, no effect was observed on the rate of disappearance of labeled immature BAPP (Fig. 2A). However, the levels of labeled matured forms of BAPP decreased and the levels of labeled peptides of 15 kDa and 19 kDa were increased (Fig. 2B,C). The 15 kDa and 19 kDa peptides were not observed when immunoprecipitation was carried out in the presence of 100 μ M β APP⁶⁴⁵⁻⁶⁹⁴ peptide (Fig.

1A, lane 6), consistent with these proteins being COOH-terminal fragments of the mature β APP. Another phorbol ester, PMA, produced effects similar to those of PDBu, while the inactive PBDu analogue, 4 α PBDu was without effect (not shown). The decrease of labeled mature β APP and concomitant increase of the labeled 15 kDa and 19 kDa peptides evidences a precursor-product relationship between these proteins. Presumably, the 15 kDa and 19 kDa peptides are proteolytic fragments of β APP which remain associated with the cell after cleavage and secretion of the N-terminal domain. The data evidence that PKC activation increases the rate of processing of mature β APP, leading to decreased recovery of the mature β APP and increased recovery of proteolytic fragments.

H7 (100 μ M), an inhibitor of several protein kinases including protein kinase C, produced a relative increase in the levels of mature β APP (Fig. 2B). These observations are consistent with the idea that PKC stimulates the processing of mature β APP. Moreover, H7, (100 μ M) antagonized the effects of PDBu (1 μ M) in decreasing the levels of labeled mature β APP and increasing the levels of labeled 15 kDa and 19 kDa peptides (not shown).

A half-maximal effect of PDBu on the levels of labeled mature β APP was observed at about 17nM, consistent with other effects of PDBu known to be mediated by PKC. In order

to examine the effect of activation of PKC on BAPP processing when the levels of mature BAPP neared maximal levels, PDBu (1 μ M) was added after 35 minutes of chase. Rapid increases in the levels of labeled 15 kDa and 19 kDa peptides were observed (Fig. 2C), evidencing that PDBu acts to increase the rate of processing of mature BAPP.

Example 3: Regulation of BAPP Processing by Okadaic acid-sensitive Protein Phosphatases

Addition of okadaic acid (1 μ M) at the start of the chase increased the half-life of labeled immature BAPP, while the amount of labeled mature BAPP fell (Fig. 4A,B). At the same time the labeled 15 kDa and 19 kDa BAPP peptides were increased (Fig. 4C). This evidences that okadaic acid, like PDBu, increases the rate of processing of mature BAPP, but, unlike PDBu, also affects BAPP processing at earlier stages. When okadaic acid (1 μ M) was added with PDBu (1 μ M) at the start of the chase, levels of the labeled 15 kDa and 19 kDa peptides were greatly increased (Fig. 1A, lane 5). Addition of okadaic acid after 35 minutes of chase, when mature BAPP neared maximal levels, led to a rapid increase in the levels of the labeled 15 kDa and 19 kDa peptides (Fig. 5C). These results evidence that okadaic acid acts to increase the rate of processing of mature BAPP. A half-maximal effect of okadaic acid on the levels of labeled

immature and mature BAPP was observed at about 300 nM (not shown).

Applicants have confirmed the prior art premise that BAPP in PC12 cells matures over a period of 45 minutes, and that it is probably processed via a lysosomal pathway. Phorbol esters lead to an apparent stimulation in the rate of processing of mature BAPP and the formation of 15 kDa and 19 kDa peptides. Phorbol esters are believed to have an effect on the rate of catabolism of these peptides. Applicants' results suggest that PKC may target BAPP for internalization and degradation, analogous to its effects in regulating the trafficking of the epidermal growth factor receptor and interleukin-2 receptors (Oltersdorf, T. et al, (1989), JBC, 265:4492-4497). The fact that H7, an inhibitor of PKC, leads to an apparent decrease in the basal rate of processing of BAPP supports the physiological significance of this reaction.

It has been reported that the extracellular portion of BAPP is normally secreted after BAPP is cleaved within the B/A4 domain (Sisodia, S.S., Kou, E.H., Beyreuther, K., Unterbeck, A. and Price, D.L., (1980), Science, 248:492-495). This means that normal BAPP processing precludes amyloidogenesis and, presumably, cerebral plaque formation. The 15 kDa and 19 kDa peptides have apparent molecular weights consistent with their

containing the entire β /A4 sequence and therefore with their potentially being amyloidgenic.

Okadaic acid, a potent inhibitor of phosphatases 1 and 2A, has been shown to increase net phosphorylation for many substrates in various experimental systems. Therefore, the effect of okadaic acid on BAPP processing cannot be attributed to any one kinase and is believed to involve phosphorylation of BAPP by kinases distinct from those characterized previously, or phosphorylation of other proteins involved in the regulation of BAPP maturation and processing.

The observation that PKC and potentially other protein kinases are involved in the regulation of normal and possibly altered processing of BAPP supports the role of abnormal phosphorylation in the amyloidogenesis of Alzheimer's disease.

It will be appreciated that the instant specification and examples are set forth by way of illustration and not limitation, and that various modifications and changes may be made without departing from the spirit and scope of the present invention.

CLAIMS

1. Use of a kinase modulator or a phosphatase modulator, said modulator being capable of increasing or decreasing the rate of proteolytic processing of said proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques in the manufacture of a medicament for regulating phosphorylation of said proteins.
2. Use according to claim 1, wherein said proteins are selected from the group consisting of β A4 amyloid precursor protein, tau and a neurofilament protein.
3. Use according to claim 1, wherein said modulator is a kinase stimulator selected from the group consisting of a phorbol ester, an indolactam, mezerin, diacrylglycerol or forskolin.
4. Use according to claim 3, wherein said modulator is a phorbol ester selected from the group consisting of 4- α -phorbol 12,13-dibutyrate, phorbol-12,13-dibutryate and phorbol 12-myristate 13-acetate.
5. Use according to claim 1, wherein the modulator is (-)-7-octylindolactam V.
6. Use according to claim 1, wherein said modulator is a kinase inhibitor selected from the group consisting of staurosporine, auranofin, W5, W12, W13, W7, H7, H8, H9, HA1004, sphingosine and tyrphostin.

7. Use according to claim 1, wherein said modulator is a phosphatase inhibitor selected from the group consisting of okadaic acid, a derivative of okadaic acid, calyculin-A and vanadate.

8. Use according to claim 1, wherein said modulator is a somatostatin analog.

9. Use of at least one inhibitor of protein phosphatase, said inhibitor being capable of decreasing the proteolytic processing of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques, in the manufacture of a medicament for inhibiting production of Alzheimer type amyloidosis in a mammal.

10. Use according to claim 9, wherein said inhibitor of protein phosphatase is okadaic acid, a derivative of okadaic acid, calyculin-A and vanadate.

11. Use of at least one agent capable of modulating the phosphorylation of proteins in mammalian cells, in the manufacture of a medicament for treating amyloidosis associated with Alzheimer's disease in a mammalian patient.

12. A pharmaceutical composition for regulating phosphorylation of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques comprising an effective amount of a kinase modulator or a phosphatase modulator, said modulator being capable of

increasing or decreasing the rate of proteolytic processing of said proteins, in association with a pharmaceutically acceptable carrier.

13. A pharmaceutical composition according to claim 12, wherein the proteins are selected from the group consisting of β A4 amyloid precursor protein, tau and a neurofilament protein.

14. A pharmaceutical composition according to claim 12 or 13, wherein said modulator is a kinase stimulator selected from the group consisting of a phorbol ester, an indolactam, mezerin, diacrylglycerol or forskolin.

15. A pharmaceutical composition according to claim 14, wherein said modulator is a phorbol ester selected from the group consisting of 4- α -phorbol 12,13-dibutyrate, phorbol-12,13-dibutryate and phorbol 12-myristate 13-acetate.

16. A pharmaceutical composition according to claim 12, wherein the modulator is (-)-7-octylindolactam V.

17. A pharmaceutical composition according to claim 12, wherein said modulator is a kinase inhibitor selected from the group consisting of staurosporine, auranofin, W5, W12, W13, W7, H7, H8, H9, HA1004, sphingosine and tyrphostin.

18. A pharmaceutical composition according to claim 12, wherein said modulator is a phosphatase inhibitor

selected from the group consisting of okadaic acid, a derivative of okadaic acid, calyculin-A and vanadate.

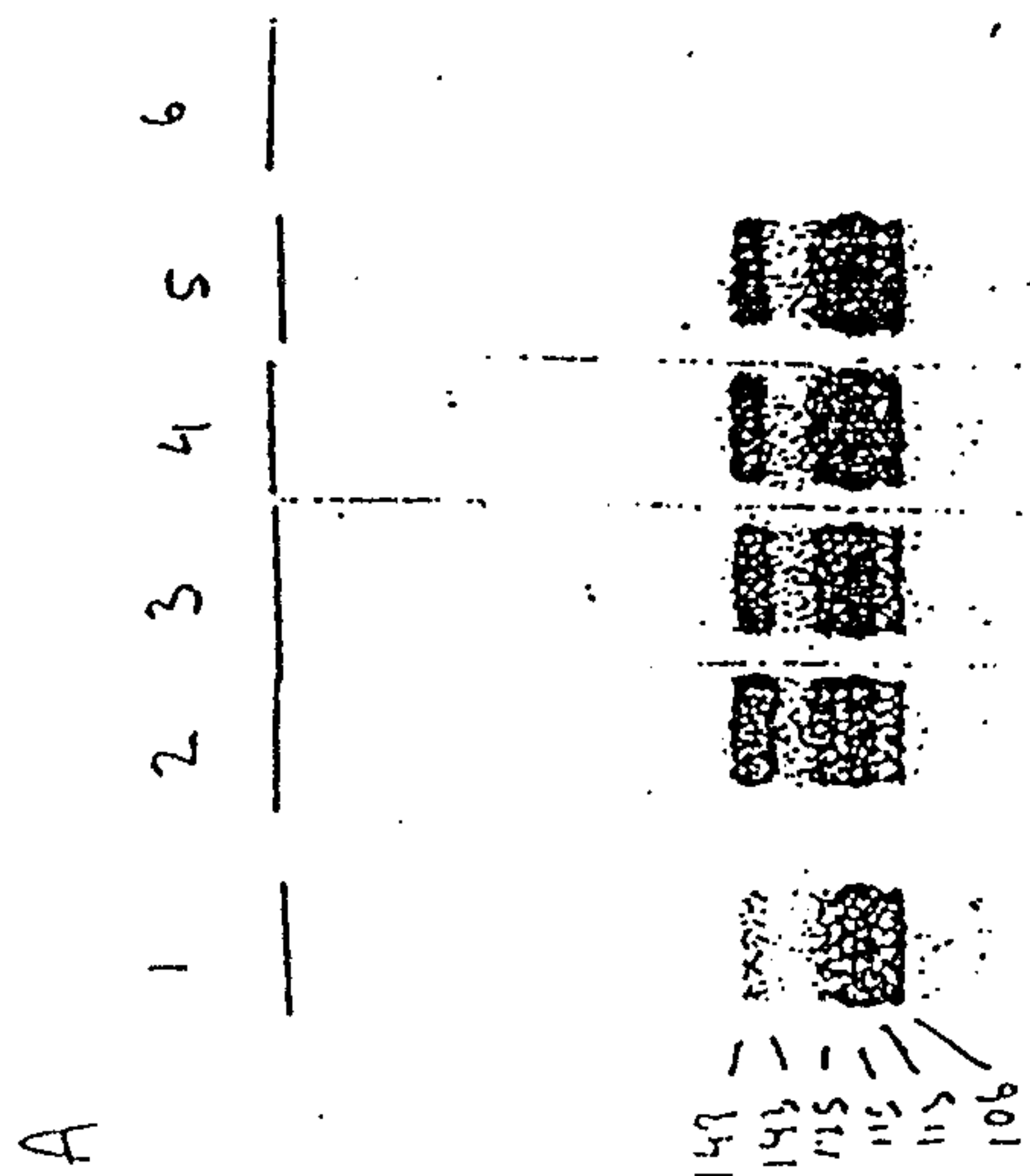
19. A pharmaceutical composition according to claim 12, wherein said modulator is a somatostatin analog.

20. A pharmaceutical composition for inhibiting production of Alzheimer type amyloidosis in a mammal comprising an effective amount of at least one inhibitor of protein phosphatase, said inhibitor being capable of decreasing the proteolytic processing of proteins found in intracellular neurofibrillary tangles and extracellular amyloid plaques, in association with a pharmaceutically acceptable carrier.

21. A pharmaceutical composition according to claim 20, wherein said inhibitor of protein phosphatase is okadaic acid, a derivative of okadaic acid, calyculin-A and vanadate.

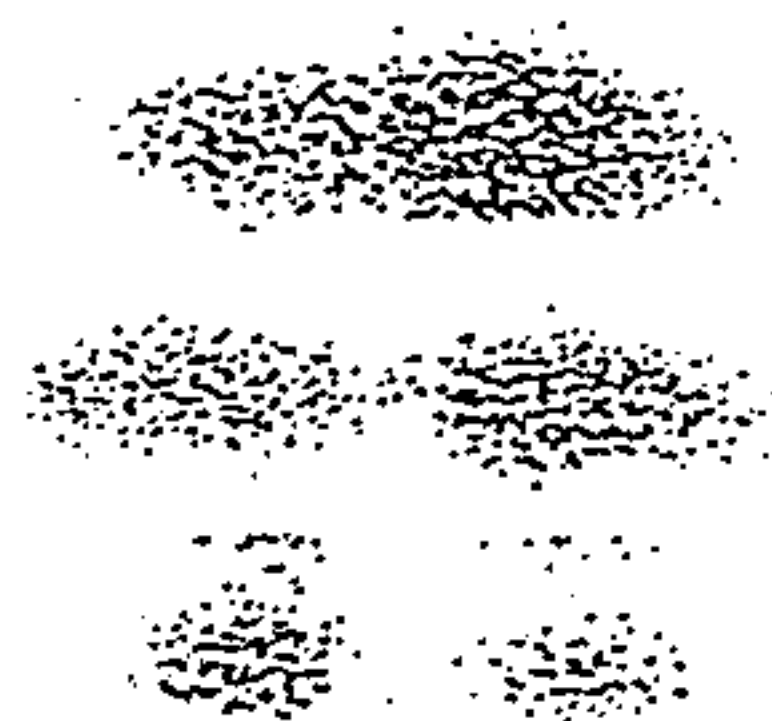
22. A pharmaceutical composition for treating amyloidosis associated with Alzheimer's disease in a mammalian patient comprising an effective amount of at least one agent capable of modulating the phosphorylation of proteins in mammalian cells, in association with a pharmaceutically acceptable carrier.

Fig 1



B

1	2	3



13

15

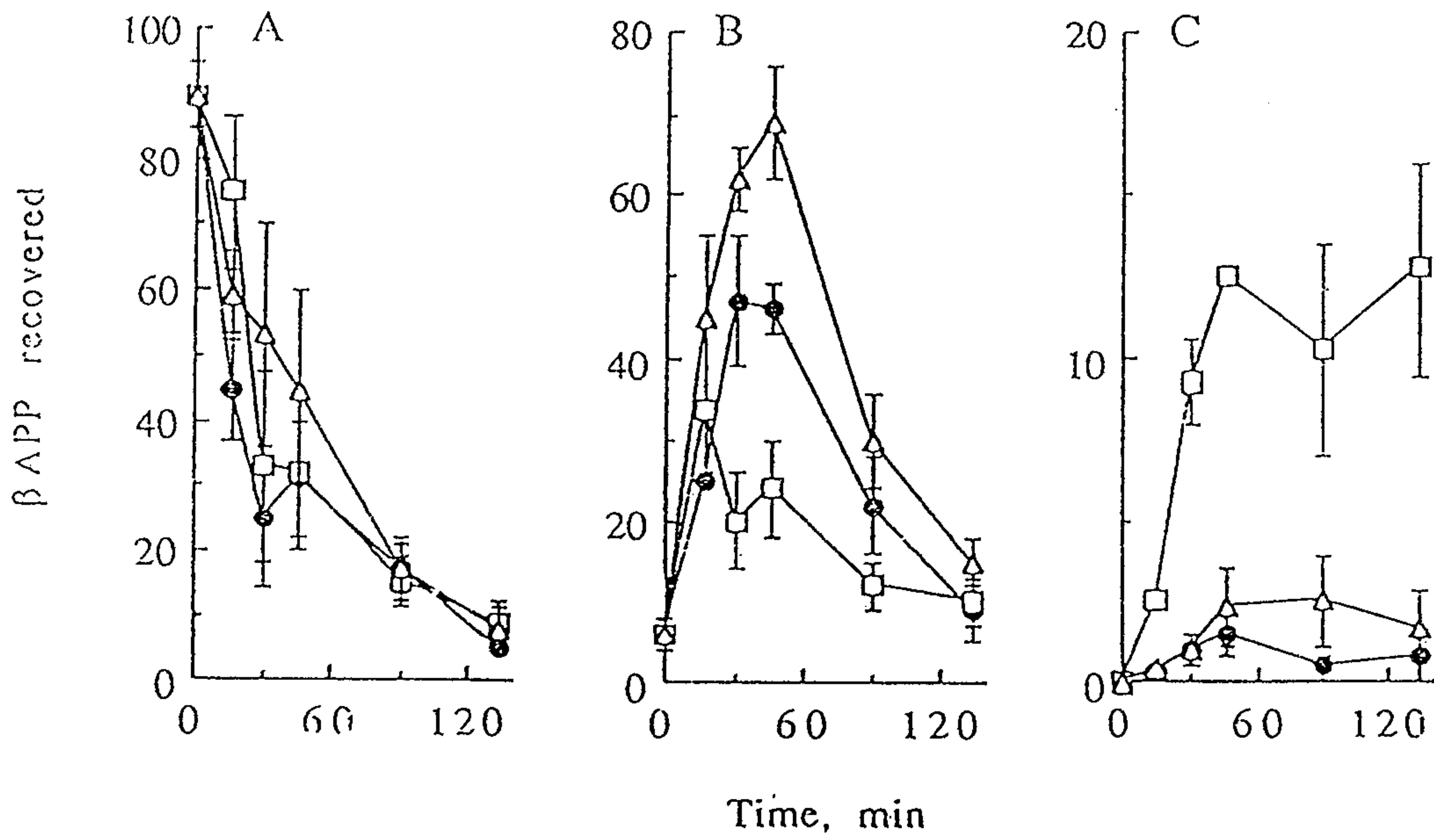


Fig. 2

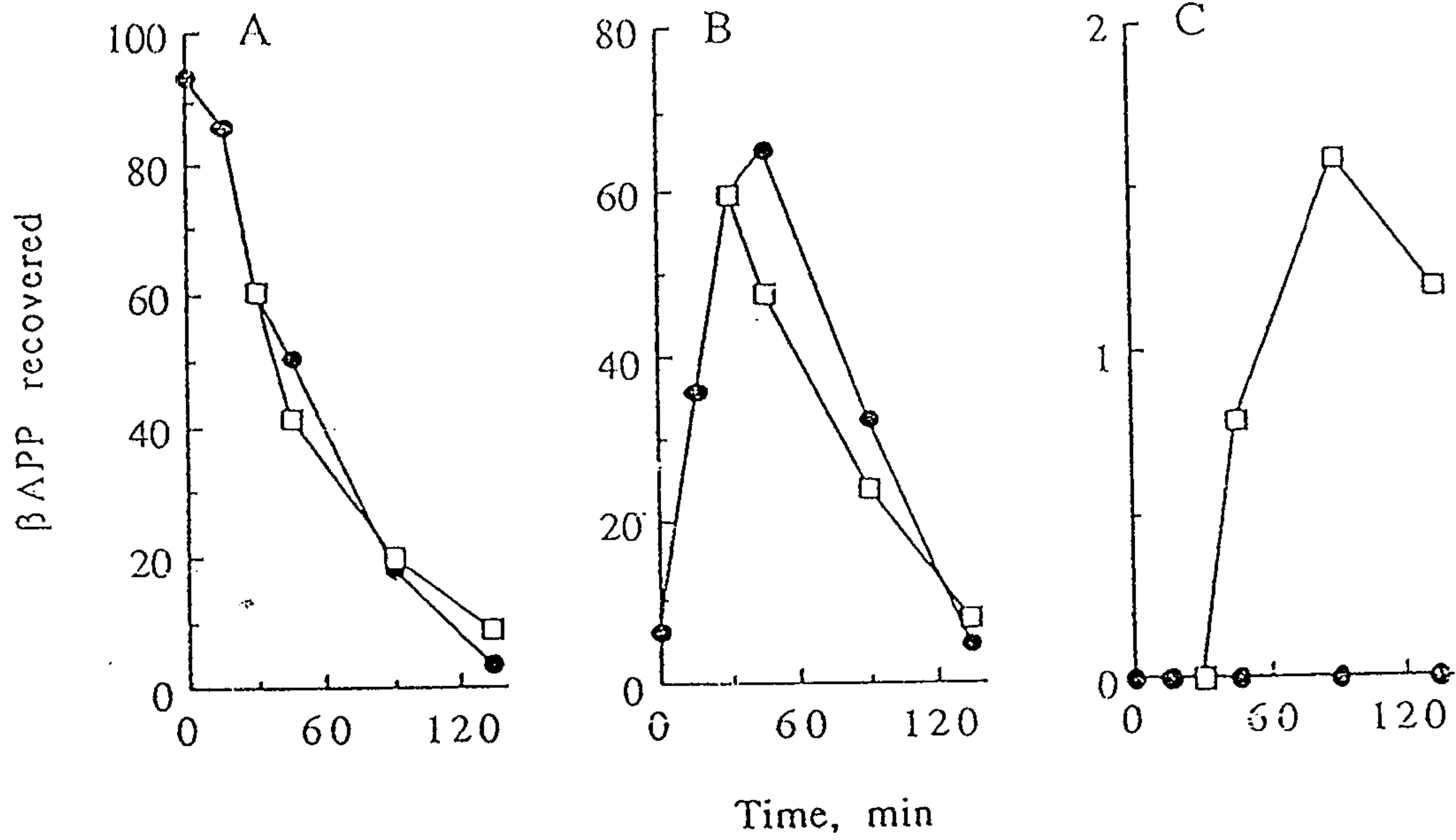


Fig. 3

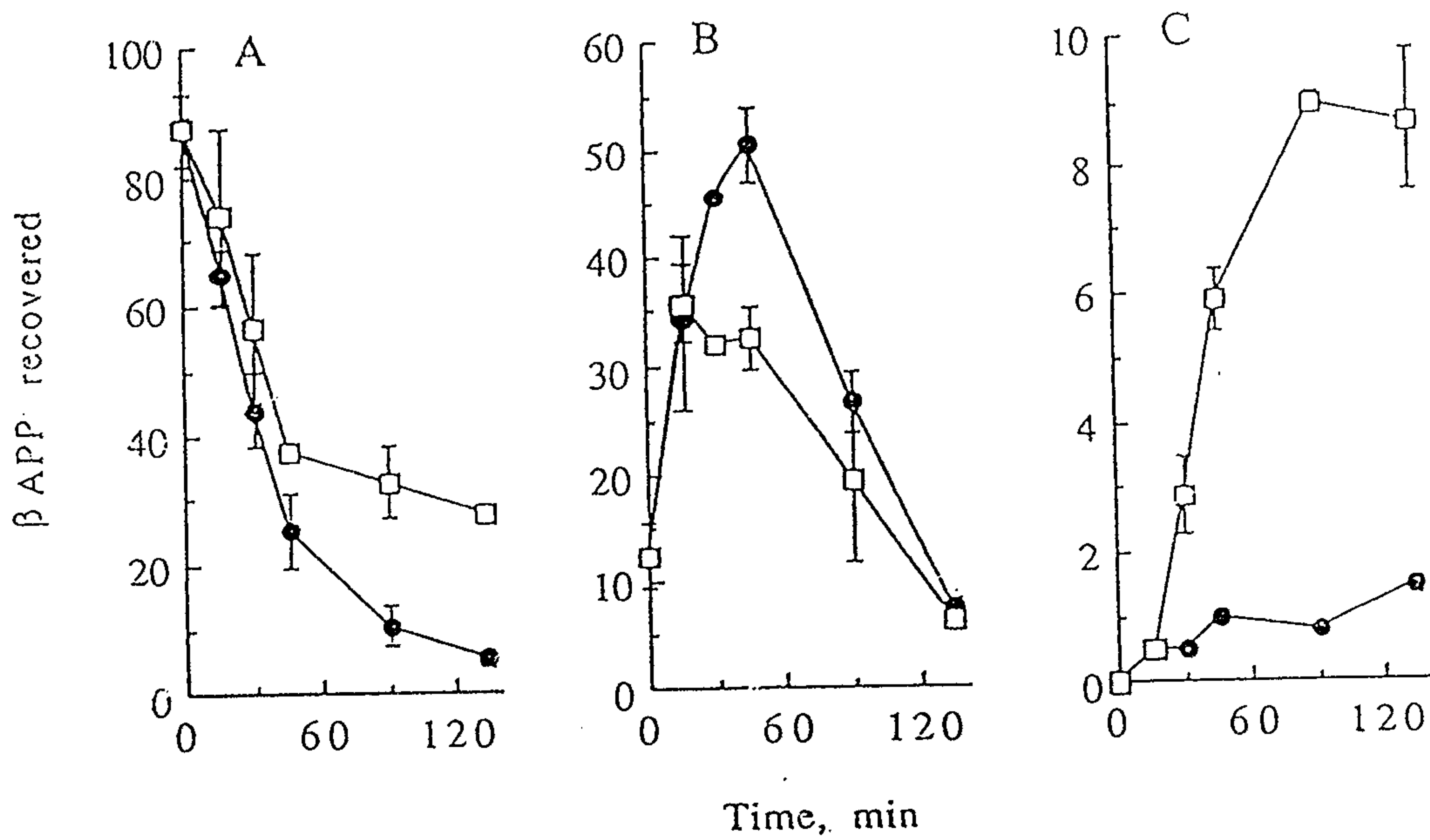


Fig. 4

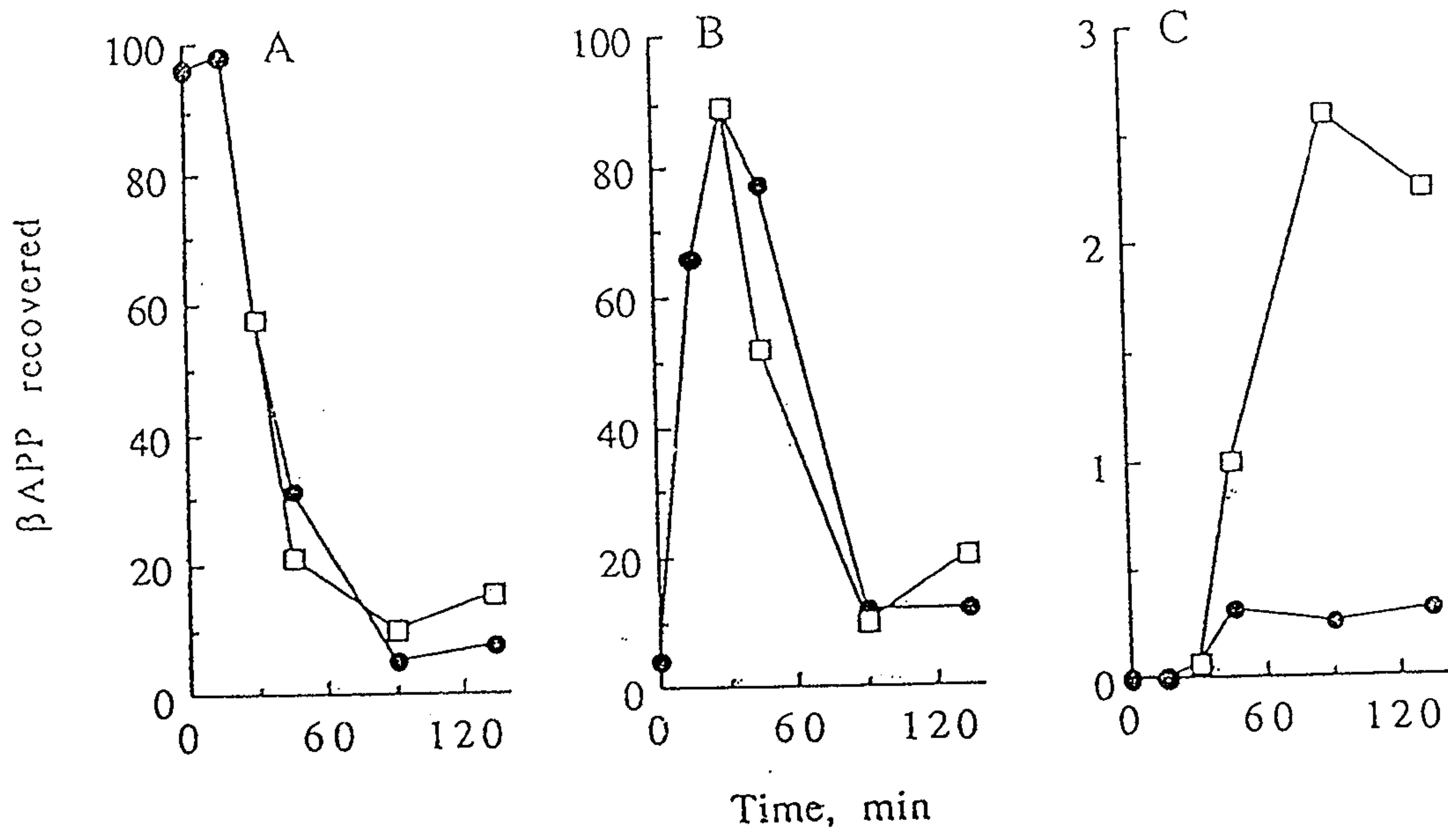


Fig. 5