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(57) **Abrégé/Abstract:**

Neurotransmission by excitatory amino acids (EAAs) such as glutamate is mediated via membrane-bound surface receptors. DNA coding for one family of the kainate-binding type of EAA receptor, has now been isolated and the receptor protein characterized. Herein described are recombinant cell lines which produce the EAA receptor as a heterologous membrane-bound product. Also described are related aspects of the invention, which are of commercial significance. Included is use of the cell lines as a tool for discovery of compounds which modulate EAA receptor stimulation.



ABSTRACT OF THE DISCLOSURE

Neurotransmission by excitatory amino acids (EAAs) such as glutamate is mediated via membrane-bound surface receptors. DNA coding for one family of the kainate-binding type of EAA receptor, has now been isolated and the receptor protein characterized. Herein described are recombinant cell lines which produce the EAA receptor as a heterologous membrane-bound product. Also described are related aspects of the invention, which are of commercial significance. Included is use of the cell lines as a tool for discovery of compounds which modulate EAA receptor stimulation.

KAINATE-BINDING, HUMAN CNS RECEPTORS OF THE EAA3 FAMILY

Field of the Invention

This invention relates to applications of recombinant DNA technology in the field of neurobiology. More particularly, the invention relates to the cloning and expression of DNA coding for excitatory amino acid (EAA) receptors, especially human EAA receptors.

Background to the Invention

In the mammalian central nervous system (CNS), the transmission of nerve impulses is controlled by the interaction between a neurotransmitter substance released by the "sending" neuron which then binds to a surface receptor on the "receiving" neuron, to cause excitation thereof. L-glutamate is the most abundant neurotransmitter in the CNS, and mediates the major excitatory pathway in vertebrates. Glutamate is therefore referred to as an excitatory amino acid (EAA) and the receptors which respond to it are variously referred to as glutamate receptors, or more commonly as EAA receptors.

Using tissues isolated from mammalian brain, and various synthetic EAA receptor agonists, knowledge of EAA receptor pharmacology has been refined somewhat. Members of the EAA receptor family are now grouped into three main types based on differential binding to such agonists. One type of EAA receptor, which in addition to glutamate also binds the agonist NMDA (N-methyl-D-aspartate), is referred to as the NMDA type of EAA receptor. Two other glutamate-binding types of EAA receptor, which do not bind NMDA, are named according to their preference for binding with two other EAA receptor agonists, namely AMPA (α -amino-3-hydroxy-5-methyl-isoxazole-4-propionate), and kainate (2-carboxy-4-(1-methylethenyl)-3-pyrrolidineacetate). Particularly, receptors which bind glutamate but not NMDA, and which bind with greater affinity to kainate than to AMPA, are referred to as kainate type EAA receptors. Similarly, those EAA receptors which bind glutamate but not NMDA, and which bind AMPA with greater affinity than kainate are referred to as AMPA type EAA receptors.

The glutamate-binding EAA receptor family is of great physiological and medical importance. Glutamate is involved in many aspects of long-term potentiation (learning and memory), in the development of synaptic plasticity, in epileptic seizures, in neuronal damage caused by ischemia following stroke or other hypoxic events, as well as in other forms of neurodegenerative processes.

However, the development of therapeutics which modulate these processes has been very difficult, due to the lack of any homogeneous source of receptor material with which to discover selectively binding drug molecules, which interact specifically at the interface of the EAA receptor. The brain derived tissues
5 currently used to screen candidate drugs are heterogeneous receptor sources, possessing on their surface many receptor types which interfere with studies of the EAA receptor/ligand interface of interest. The search for human therapeutics is further complicated by the limited availability of brain tissue of human origin. It would therefore be desirable to obtain cells that are genetically engineered to
10 produce only the receptor of interest. With cell lines expressing cloned receptor genes, a substrate which is homogeneous for the desired receptor is provided, for drug screening programs.

Non-human cDNAs which appear to encode the kainate-type of receptor have been reported. Egebjerg *et al.* (Nature 351: 745, 1991) and WO91/06648,
15 each describe the isolation of a cDNA from rat called GluR6 which, although related by sequence to AMPA receptor genes, forms a receptor which is not activated by AMPA but rather by glutamate, quisqualate, and preferentially, kainate. Other kainate binding proteins, which do not readily exhibit ion channel properties when expressed in a homomeric fashion, have also been cloned from
20 frog (Wada *et al.*, Nature 342: 684, 1989), chicken (Gregor *et al.*, Nature 342: 689, 1989; Eshar *et al.*, FEBS Lett. 297: 257, 1992), mouse (Sakimura *et al.*, Neuron 8: 267, 1992) and rat (Werner *et al.*, Nature 351: 742, 1991; Bettler *et al.*, Neuron 8: 257, 1992; Herb *et al.*, Neuron 8: 775, 1992).

There has emerged from these molecular cloning advances a better
25 understanding of the structural features of EAA receptors and their subunits, as they exist in the rat brain. According to the current model of EAA receptor structure, each is heteromeric in structure, consisting of individual membrane-anchored subunits, each having four transmembrane regions, and extracellular domains that dictate ligand binding properties to some extent and contribute to the
30 ion-gating function served by the receptor complex.

In the search for therapeutics useful to treat CNS disorders in humans, it is highly desirable to obtain knowledge of human EAA receptors. A specific

understanding of human receptors would provide a means to screen for compounds that react therewith, i.e. to stimulate or inhibit receptor activity, and thus, provides a means to identify compounds having potential therapeutic utility in humans. Non-human mammalian models are not suitable for this purpose despite significant receptor sequence homology as minute sequence differences between species homologues of the same receptor from different species can cause dramatic pharmacological variation (Oksenberg *et al.*, Nature, 360: 161, 1992). It is therefore particularly desirable to provide cloned cDNA encoding human EAA receptors, and cell lines expressing these receptors in a homogeneous fashion, in order to generate a proper screening method for compounds therapeutically useful in humans. These, accordingly, are objects of the present invention.

It is another object of the present invention to provide in isolated form a DNA molecule which codes for a human EAA receptor.

It is another object of the present invention to provide a cell that has been genetically engineered to produce a kainate-binding human EAA receptor.

Other objects of the present invention will be apparent from the following description of the invention.

Summary of the Invention

Polynucleotides coding for a family of EAA receptors which in addition to binding glutamate with an affinity typical of EAA receptors, also exhibit ligand binding properties characteristic of kainate-type EAA receptors, have now been identified and characterized. A representative member of this human EAA receptor family is herein designated human EAA3a. Sequence-related polynucleotides coding for variants of the human EAA3a receptor have also been identified, and constitute additional members of this receptor family, herein referred to as the human EAA3 receptor family.

The present invention thus provides, in one of its aspects, an isolated polynucleotide, consisting either of DNA or of RNA, which codes for a human EAA3 receptor or for a kainate-binding fragment thereof.

In another aspect of the present invention, there is provided a cell that has been genetically engineered to produce a kainate-binding, human EAA receptor

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belonging to the herein-defined EAA3 family. In related aspects of the present invention, there are provided recombinant DNA constructs and relevant methods useful to create such cells.

5 In another aspect of the present invention, there is provided a method for evaluating interaction between a test ligand and a human EAA receptor, which comprises the steps of incubating the test ligand with a genetically engineered cell of the present invention, or with a membrane
10 preparation derived therefrom, and then assessing said interaction by determining receptor/ligand binding.

 Thus in one aspect, there is described an isolated polynucleotide that codes for a human EAA3 receptor, selected from the group consisting of: a) a human EAA3a
15 receptor having the amino acid sequence shown in Figure 1, b) a human EAA3b receptor having the amino acid sequence shown in Figure 1, with the exception that the aspartate residue at position 639 is an asparagine residue, c) a human EAA3c receptor having the amino acid sequence of Figure 1,
20 with the exception that 40 amino acids have been deleted from the C-terminus and amino acid residues 826 to 836 are as shown in Fig. 4B, d) a human EAA3d receptor having the amino acid sequence of Figure 1, with the exception that amino acid residues 6 to 61 are deleted, and e) a human EAA3
25 receptor having an amino acid sequence having at least 97 percent sequence identity to the amino acid sequence of any one of (a), (b), (c) or (d).

 In another aspect, there is described an isolated protein selected from the group consisting of: a) a human
30 EAA3a receptor having the amino acid sequence shown in Figure 1, b) a human EAA3b receptor having the amino acid

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sequence shown in Figure 1, with the exception that the aspartate residue at position 639 is an asparagine residue, c) a human EAA3c receptor having the amino acid sequence of Figure 1, with the exception that 40 amino acids have been
5 deleted from the C-terminus and amino acid residues 826 to 836 are as shown in Fig. 4B, d) a human EAA3d receptor having the amino acid sequence of Figure 1, with the exception that amino acid residues 6 to 61 are deleted, and e) a human EAA3 receptor having an amino acid sequence
10 having at least 97 percent sequence identity to the amino acid sequence of any one of (a), (b), (c) or (d).

In another aspect, there is described an isolated human EAA3a receptor having the amino acid sequence shown in Figure 1.

15 In another aspect, there is described an isolated human EAA3b receptor having the amino acid sequence shown in Figure 1, with the exception that the aspartate residue at position 639 is an asparagine residue.

In another aspect, there is described an isolated
20 human EAA3c receptor having the amino acid sequence of Figure 1, with the exception that 40 amino acids have been deleted from the C-terminus and amino acid residues 826 to 836 are as shown in Fig. 4B.

In another aspect, there is described an isolated
25 human EAA3d receptor having the amino acid sequence of Figure 1, with the exception that amino acid residues 6 to 61 are deleted.

In another aspect, there is described a membrane preparation derived from the cell of the invention, wherein
30 said membrane preparation comprises the protein of the

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invention, or the receptor of the invention, or the fragment of the invention.

In another aspect, there is described a process for obtaining a substantially homogeneous source of a human
5 EAA receptor, which comprises the steps of culturing cells having incorporated expressibly therein the polynucleotide of the invention, and then recovering the EAA3 receptor from the cultured cells.

In another aspect, there is described a method of
10 assaying a test ligand for interaction with a human CNS receptor, which comprises the steps of incubating the test ligand under appropriate conditions with the human EAA receptor-producing cell of the invention, or with the membrane preparation of the invention, and then determining
15 one of the extent of binding between the human EAA3 receptor and the test ligand, or the ligand-induced electrical current across said cell or membrane.

Other aspects of the present invention, which encompass various applications of the discoveries herein
20 described, will become apparent from the following detailed description, and from the accompanying drawings, in which:

Brief Reference to the Drawings

Figure 1 provides the nucleotide sequence of a cDNA insert comprising DNA coding for an excitatory amino
25 acid receptor of the present invention, and the deduced amino acid sequence thereof;

Figure 2 illustrates with plasmid maps the strategy used to construct a vector harbouring the full-length DNA sequence illustrated in Figure 1;

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Figure 3 illustrates with plasmid maps the strategy used to construct expression vectors harbouring the DNA sequence illustrated in Figure 1;

Figures 4A-4C show, with reference to Figure 1, compare the DNA and amino acid sequences of naturally occurring variants to the DNA sequence of the EAA receptor illustrated in Figure 1; and

Figures 5 and 6 illustrate the ligand-binding properties of an EAA receptor expressed from the coding region provided in Figure 1.

Detailed Description of the Invention and its Preferred Embodiments

The invention relates to excitatory amino acid (EAA) receptors of human origin, and is directed more particularly to a novel family of kainate-type human EAA receptors, herein designated the human EAA3 receptor family. As used herein, the term "human EAA3 receptor" is intended to embrace the human EAA3a receptor, and kainate-binding variants of the EAA3a receptor that are structurally related thereto, i.e. share at least 97% amino acid identity including naturally occurring and synthetically derived variants of the EAA3a receptor.

Naturally occurring variants of the human EAA3a receptor include particularly the receptors herein designated EAA3b, EAA3c and EAA3d. Synthetically derived variants of the human EAA3a receptor include kainate-binding variants that incorporate one or more, e.g. 1-56, amino acid deletions or additions relative to the EAA3a receptor, or one or more amino acid substitutions, e.g. 1-32 amino acid substitutions relative to the EAA3a receptor.

The term "kainate-binding", as it is used herein with respect to EAA3 receptors, and variants and fragments thereof, is meant to encompass those receptors, variants and fragments that display greater binding affinity for kainate than for either glutamate, AMPA or NMDA, as determined in assays of conventional design, such as the assays herein described.

Each of the naturally occurring members of the EAA3 receptor family possesses structural features characteristic of EAA receptors in general, including extracellular amino (N-) and carboxy-terminal (C-terminal) regions, as well as four internal hydrophobic domains which serve to anchor the receptor within the cell surface membrane. The particular human EAA receptor designated EAA3a is a protein characterized structurally as a single polypeptide chain that is produced initially in precursor form bearing a 30 residue N-terminal signal peptide, and is transported to the cell surface in mature form i.e. lacking the signal peptide and consisting of 875 amino acids arranged in the sequence illustrated, by single letter code, in Figure 1. Unless otherwise stated, the term "EAA3 receptor" refers to the mature form of the receptor protein, and amino acid residues of EAA3 receptors are accordingly numbered with reference to the mature protein sequence. With respect to structural domains of the receptor, hydropathy analysis reveals four putative transmembrane domains, one spanning residues 533-552 inclusive (TM-1), another spanning residues 574-594 (TM-2), a third spanning residues 605-623 (TM-3) and the fourth spanning residues 790-810 (TM-4). Based on this assignment, it is likely that the human EAA3a receptor structure, in its natural membrane-bound form, consists of a 532 amino acid N-terminal extracellular domain, followed by a hydrophobic region containing the four transmembrane domains and an extracellular, 65 amino acid C-terminal domain.

As shown in Figures 4A-4C, three structurally related variants of the EAA3a receptor, which occur naturally in human brain tissue, have also been identified and are herein designated the EAA3b, EAA3c and EAA3d receptors. As deduced from nucleotide sequences of the genes coding for them, the EAA3b variant shares greater than 99% amino acid identity with EAA3a, differing only by a single amino acid at position 639 which is an aspartate residue in the EAA3a receptor and an asparagine residue in the EAA3b receptor (Fig. 4A). The EAA3c receptor, on the other hand, is a truncated version of EAA3a in which 40 amino acids have been eliminated from the C-terminus. Additionally, the last eleven amino acid residues at the C-terminus of EAA3c, i.e. amino acids at positions 826 to 836, differ from those in the corresponding region of EAA3a as shown in Fig. 4B. In comparison to EAA3a, the EAA3d receptor has a 56 amino acid deletion at its N-terminal end, i.e. the amino acids at positions 6 to 61 in EAA3a are deleted from EAA3d (Fig. 4C).

Like other members of the human EAA3 receptor family, EAA3a is characterized by a pharmacological profile i.e. a ligand binding "signature", that points strongly to a kainate-type pharmacology, as distinct from other excitatory amino acid receptor types, such as NMDA and AMPA. In addition, and despite the understanding that kainate binding receptors require a multi- and perhaps heteromeric subunit structure to function in the pharmacological sense, it has been found that cells producing the unitary EAA3a receptor do, independently of association with other receptor subunits, provide a reliable indication of excitatory amino acid binding. Thus, in a key aspect of the present invention, the human EAA3a receptor is exploited for the purpose of screening candidate compounds for the ability to interact with the present receptors and/or the ability to compete with endogenous EAA receptor ligands and known synthetic analogues thereof, for EAA receptor interaction.

For use in assessing interaction between the receptor and a test ligand, it is desirable to construct by application of genetic engineering techniques a cell that produces a human EAA3 receptor in functional form as a heterologous product. The construction of such cell lines is achieved by introducing into a selected host cell a recombinant DNA construct in which DNA coding for a

secretable form of the human EAA3 receptor, i.e., a form bearing either its native signal peptide or a functional, heterologous equivalent thereof, is associated with expression controlling elements that are functional in the selected host to drive expression of the receptor-encoding DNA, and thus elaborate the desired EAA3 receptor protein. Such cells are herein characterized as having the receptor-encoding DNA incorporated "expressibly" therein. The receptor-encoding DNA is referred to as "heterologous" with respect to the particular cellular host if such DNA is not naturally found in the particular host.

It is most desirable to use a mammalian cell host to produce EAA3 receptors due to the mammalian origin of the present human EAA3 receptors; however, other suitably engineered eukaryotic and prokaryotic hosts may also be employed to produce EAA3 receptors. Accordingly, bacterial hosts such as E. coli and B. subtilis, fungal hosts such as Aspergillus and yeast and insect cell hosts such as Spodoptera frugiperda, are examples of non-mammalian hosts that may also be used to produce EAA3 receptors of the present invention.

The particular cell type selected to serve as host for production of the human EAA3 receptor can be any of several cell types currently available in the art, but should not of course be a cell type that in its natural state elaborates a surface receptor that can bind excitatory amino acids, and so confuse the assay results sought from the engineered cell line. Generally, such problems are avoided by selecting as host a non-neuronal cell type, and can further be avoided using non-human cell lines, as is conventional. It will be appreciated that neuronal- and human-type cells may nevertheless serve as expression hosts, provided that "background" binding to the test ligand is accounted for in the assay results.

According to one embodiment of the present invention, the cell line selected to serve as host for EAA3 receptor production is a mammalian cell. Several types of such cell lines are currently available for genetic engineering work, and these include the chinese hamster ovary (CHO) cells for example of K1 lineage (ATCC CCL 61) including the Pro5 variant (ATCC CRL 1281); the fibroblast-like cells derived from SV40-transformed African Green monkey kidney of the CV-1 lineage (ATCC CCL 70), of the COS-1 lineage (ATCC CRL 1650) and of

the COS-7 lineage (ATCC CRL 1651); murine L-cells, murine 3T3 cells (ATCC CRL 1658), murine C127 cells; human embryonic kidney cells of the 293 lineage (ATCC CRL 1573), human carcinoma cells including those of the HeLa lineage (ATCC CCL 2), and neuroblastoma cells of the lines IMR-32 (ATCC CCL 127),
5 SK-N-MC (ATCC HTB 10) and SK-N-SH (ATCC HTB 11).

A variety of gene expression systems have been adapted for use with these hosts and are now commercially available, and any one of these systems can be exploited to drive expression of the EAA3 receptor-encoding DNA. These systems, available typically in the form of plasmidic vectors, incorporate
10 expression cassettes the functional components of which include DNA constituting expression controlling sequences, which are host-recognized and enable expression of the receptor-encoding DNA when linked 5' thereof. The systems further incorporate DNA sequences which terminate expression when linked 3' of the receptor-encoding region. Thus, for expression in the selected mammalian cell
15 host, there is generated a recombinant DNA expression construct in which DNA coding for a secretable form of the receptor is linked with expression controlling DNA sequences recognized by the host, and which include a region 5' of the receptor-encoding DNA to drive expression, and a 3' region to terminate expression. The plasmidic vector harbouring the expression construct typically
20 incorporates such other functional components as an origin of replication, usually virally-derived, to permit replication of the plasmid in the expression host and desirably also for plasmid amplification in a bacterial host, such as E.coli. To provide a marker enabling selection of stably transformed recombinant cells, the vector will also incorporate a gene conferring some survival advantage on the
25 transformants, such as a gene coding for neomycin resistance in which case the transformants are plated in medium supplemented with neomycin.

Included among the various recombinant DNA expression systems that can be used to achieve mammalian cell expression of the receptor-encoding DNA are those that exploit promoters of viruses that infect mammalian cells, such as the
30 promoter from the cytomegalovirus (CMV), the Rous sarcoma virus (RSV), simian virus (SV40), murine mammary tumor virus (MMTV) and others. Also useful to drive expression are promoters such as the LTR of retroviruses, insect

cell promoters such as those regulated by temperature, and isolated from *Drosophila*, as well as mammalian gene promoters such as steroid-inducible promoters and those regulated by heavy metals i.e. the metallothionein gene promoter.

5 For incorporation into the recombinant DNA expression vector, DNA coding for the desired EAA3 receptor, e.g. the EAA3a receptor or a kainate-binding variant thereof, can be obtained by applying selected techniques of gene isolation or gene synthesis. As described in more detail in the examples herein, the EAA3a receptor, and the EAA3b, EAA3c, and EAA3d variants thereof, are
10 encoded within the genome of human brain tissue, and can therefore be obtained by careful application of conventional gene isolation and cloning techniques. This typically will entail extraction of total messenger RNA from a fresh source of human brain tissue, such as cerebellum or hippocampus tissue and preferably fetal brain tissue, followed by conversion of message to cDNA and formation of a
15 library in for example a bacterial plasmid, more typically a bacteriophage. Such bacteriophage harbouring fragments of the human DNA are typically grown by plating on a lawn of susceptible *E. coli* bacteria, such that individual phage plaques or colonies can be isolated. The DNA carried by the phage colony is then typically immobilized on a nitrocellulose or nylon-based hybridization membrane,
20 and then hybridized, under carefully controlled conditions, to a radioactively (or otherwise) labelled oligonucleotide probe of appropriate sequence to identify the particular phage colony carrying receptor-encoding DNA or fragment thereof. Typically, the gene or a portion thereof so identified is subcloned into a plasmidic vector for nucleic acid sequence analysis.

25 Having herein provided the nucleotide sequence of various human EAA3 receptors, it will be appreciated that automated techniques of gene synthesis and/or amplification can be performed to generate DNA coding therefor. Because of the length of EAA3 receptor-encoding DNA, application of automated synthesis may require staged gene construction, in which regions of the gene up to about
30 300 nucleotides in length are synthesized individually and then ligated in correct succession for final assembly. Individually synthesized gene regions can be amplified prior to assembly, using polymerase chain reaction (PCR) technology.

The application of automated gene synthesis techniques provides an opportunity for generating sequence variants of naturally occurring members of the EAA3 gene family. It will be appreciated that polynucleotides coding for the EAA3 receptors herein described can be generated by substituting synonymous
5 codons for those represented in the naturally occurring polynucleotide sequences herein identified. In addition, polynucleotides coding for synthetic variants of the EAA3 receptors herein described can be generated which for example incorporate one or more single amino acid substitutions, deletions or additions. Since it will for the most part be desirable to retain the natural ligand binding profile of the
10 receptor for screening purposes, it is desirable to limit amino acid substitutions, for example to the so-called conservative replacements in which amino acids of like charge are substituted, and to limit substitutions to those sites less critical for receptor activity e.g. within about the first 20 N-terminal residues of the mature receptor, and such other regions as are elucidated upon receptor domain mapping.

15 With appropriate template DNA in hand, the technique of PCR amplification may also be used to directly generate all or part of the final gene. In this case, primers are synthesized which will prime the PCR amplification of the final product, either in one piece, or in several pieces that may be ligated together. This may be via step-wise ligation of blunt ended, amplified DNA
20 fragments, or preferentially via step-wise ligation of fragments containing naturally occurring restriction endonuclease sites. In this application, it is possible to use either cDNA or genomic DNA as the template for the PCR amplification. In the former case, the cDNA template can be obtained from commercially available or self-constructed cDNA libraries of various human brain tissues,
25 including hippocampus and cerebellum.

Once obtained, the receptor-encoding DNA is incorporated for expression into any suitable expression vector, and host cells are transfected therewith using conventional procedures, such as DNA-mediated transformation, electroporation, microinjection, or particle gun transformation. Expression vectors may be
30 selected to provide transformed cell lines that express the receptor-encoding DNA either transiently or in a stable manner. For transient expression, host cells are typically transformed with an expression vector harbouring an origin of replication

functional in a mammalian cell. For stable expression, such replication origins are unnecessary, but the vectors will typically harbour a gene coding for a product that confers on the transformants a survival advantage, to enable their selection. Genes coding for such selectable markers include the *E. coli gpt* gene which confers resistance to mycophenolic acid, the *neo* gene from transposon Tn5 which confers resistance to the antibiotic G418 and to neomycin, the *dhfr* sequence from murine cells or *E. coli* which changes the phenotype of DHFR-cells into DHFR+ cells, and the *tk* gene of herpes simplex virus, which makes TK- cells phenotypically TK+ cells. Both transient expression and stable expression can provide transformed cell lines, and membrane preparations derived therefrom, for use in ligand screening assays.

For use in screening assays, cells transiently expressing the receptor-encoding DNA can be stored frozen for later use, but because the rapid rate of plasmid replication will lead ultimately to cell death, usually in a few days, the transformed cells should be used as soon as possible. Such assays may be performed either with intact cells, or with membrane preparations derived from such cells. The membrane preparations typically provide a more convenient substrate for the ligand binding experiments, and are therefore preferred as binding substrates. To prepare membrane preparations for screening purposes, i.e., ligand binding experiments, frozen intact cells are homogenized while in cold water suspension and a membrane pellet is collected after centrifugation. The pellet is then washed in cold water, and dialyzed to remove endogenous EAA ligands such as glutamate, that would otherwise compete for binding in the assays. The dialyzed membranes may then be used as such, or after storage in lyophilized form, in the ligand binding assays. Alternatively, intact, fresh cells harvested about two days after transient transfection or after about the same period following fresh plating of stably transfected cells, can be used for ligand binding assays by the same methods as used for membrane preparations. When cells are used, the cells must be harvested by more gentle centrifugation so as not to damage them, and all washing must be done in a buffered medium, for example in phosphate-buffered saline, to avoid osmotic shock and rupture of the cells.

The EAA3 receptors of the present invention are per se functional in an electrophysiological context, and are therefore useful, in the established manner, in screening test ligands for their ability to modulate ion channel activity. The present invention thus further provides, as a ligand screening technique, a method of detecting interaction between a test ligand and a human CNS receptor, which comprises the steps of incubating the test ligand with a human EAA3 receptor-producing cell or with a membrane preparation derived therefrom, and then measuring ligand-induced electrical current across said cell or membrane.

As an alternative to using cells that express receptor-encoding DNA, ligand characterization may also be performed using cells, for example *Xenopus* oocytes, that yield functional membrane-bound receptor following introduction of messenger RNA coding for the EAA3 receptor. In this case, the EAA3 receptor gene of the invention is typically subcloned into a plasmidic vector such that the introduced gene may be easily transcribed into RNA via an adjacent RNA transcription promoter supplied by the plasmidic vector, for example the T3 or T7 bacteriophage promoters. RNA is then transcribed from the inserted gene *in vitro*, and can then be injected into *Xenopus* oocytes. Following the injection of nL volumes of an RNA solution, the oocytes are left to incubate for up to several days, and are then tested in either intact form or as a membrane preparation for the ability to bind a particular ligand molecule supplied in a bathing solution. Since functional EAA receptors act in part by operating a membrane channel through which ions may selectively pass, the functioning of the receptor in response to a particular ligand molecule in the bathing solution may typically be measured as an electrical current utilizing microelectrodes inserted into the cell or placed on either side of a cell-derived membrane preparation using the "patch-clamp" technique.

The binding of a candidate ligand to a selected human EAA3 receptor of the invention is evaluated typically using a predetermined amount of cell-derived membrane (measured for example by protein determination), generally from about 25ug to 100ug. Generally, competitive binding assays will be useful to evaluate the affinity of a test compound relative to kainate. This competitive binding assay can be performed by incubating the membrane preparation with radiolabelled

kainate, for example [3H]-kainate, in the presence of unlabelled test compound added at varying concentrations. Following incubation, either displaced or bound radiolabelled kainate can be recovered and measured, to determine the relative binding affinities of the test compound and kainate for the particular receptor used as substrate. In this way, the affinities of various compounds for the kainate-type human EAA receptors can be measured.

In addition to using the receptor-encoding DNA to construct cell lines useful for ligand screening, expression of the DNA can, according to another aspect of the invention, be performed to produce fragments of the receptor in soluble form, for structure investigation, to raise antibodies and for other experimental uses. It is expected that kainate-binding fragments, i.e., the portion of the EAA3 receptor responsible for binding a ligand molecule, resides on the outside of the cell, i.e., is extracellular. It is therefore desirable in the first instance to facilitate the characterization of the receptor-ligand interaction by providing such kainate binding fragments in quantity and in isolated form, i.e., free from the remainder of the receptor. To accomplish this, the full-length EAA3 receptor-encoding DNA may be modified by site-directed mutagenesis, to introduce a translational stop codon into the extracellular N-terminal region, immediately 5' of the first transmembrane domain (TM1), i.e., before the residue 533 codon as shown in Figure 1. Since there will no longer be produced any transmembrane domain(s) to "anchor" the receptor into the membrane, expression of the modified gene will result in the secretion, in soluble form, of only the extracellular ligand-binding domain. Standard ligand-binding assays may then be performed to ascertain the degree of binding of a candidate compound to the extracellular domain so produced. It may of course be necessary, using site-directed mutagenesis, to produce different versions of the extracellular regions, in order to map the ligand binding domain with precision. It will also be appreciated that the length of the fragment may be varied, i.e. to lengths less than the entire 533 amino acid extracellular N-terminal domain.

For use in ligand binding assays according to the present invention, kainate-binding fragments of the receptor will first be anchored to a solid support using any one of various techniques. In one method, the C-terminal end of the receptor

peptide fragment may be coupled to a derivatized, insoluble polymeric support, for example, cross-linked polystyrene or polyamide resin. Once anchored to the solid support, the fragment is useful to screen candidate ligands for receptor binding affinity. For this purpose, competition-type ligand-binding assays, as
5 described above using full-length receptor, are commonly used. Fragments secured to a solid support are bound with a natural ligand, i.e. kainate in the presence of a candidate ligand. One of kainate or candidate ligand is labelled, for example radioactively, and following a suitable incubation period, the degree of kainate displacement is determined by measuring the amount of bound or unbound
10 label.

Alternatively, it may be desirable to produce an extracellular domain of the receptor which is not derived from the N-terminus of the mature protein, but rather from the C-terminus, for example domains immediately following the fourth transmembrane domain (TM4), i.e., residing between amino acid residues
15 811 and 875 inclusive as shown in Figure 1. In this case, site-directed mutagenesis and/or PCR-based amplification techniques may readily be used to provide a defined fragment of the gene encoding the receptor domain of interest. Direct peptide synthesis may also be used to make the desired C-terminal fragment, or as noted above, desired N-terminal fragments. Such a DNA
20 sequence may be used to direct the expression of the desired receptor fragment, either intracellularly, or in secreted fashion, provided that the DNA encoding the gene fragment is inserted adjacent to a translation start codon provided by the expression vector, and that the required translation reading frame is carefully conserved.

25 It will be appreciated that the production of such extracellular ligand binding domains may be accomplished in a variety of host cells. Mammalian cells such as CHO cells may be used for this purpose, the expression typically being driven by an expression promoter capable of high-level expression, for example the CMV (cytomegalovirus) promoter. Alternately, non-mammalian cells, such
30 as insect Sf9 (*Spodoptera frugiperda*) cells may be used, with the expression typically being driven by expression promoters of the baculovirus, for example the strong, late polyhedrin protein promoter. Filamentous fungal expression

systems may also be used to secrete large quantities of such extracellular domains of the EAA receptor. Aspergillus nidulans, for example, with the expression being driven by the *alcA* promoter, would constitute such an acceptable system. In addition to such expression hosts, it will be further appreciated that any prokaryotic or other eukaryotic expression system capable of expressing heterologous genes or gene fragments, whether intracellularly or extracellularly would be similarly acceptable. For use particularly in detecting the presence and/or location of an EAA3 receptor, for example in brain tissue, the present invention also provides, in another of its aspects, labelled antibody to a human EAA3 receptor. To raise such antibodies, there may be used as immunogen either the intact, soluble receptor or an immunogenic fragment thereof, produced in a microbial or mammalian cell host as described above or by standard peptide synthesis techniques. Regions of the EAA3a receptor particularly suitable for use as immunogenic fragments include those corresponding in sequence to an extracellular region of the receptor, or a portion of the extracellular region, such as peptides consisting of residues 1-532 or fragments thereof, including particularly residues 186-201 or 485-528, and peptides corresponding to the region between transmembrane domains TM-2 and TM-3, such as a peptide consisting of residues 595-604. Peptides consisting of the C-terminal domain (residues 811-875), or fragments thereof may also be used for the raising of antibodies. Substantially the same region of the human EAA3b, EAA3c and EAA3d receptor may also be used for production of antibodies against this receptor.

The raising of antibodies to the desired EAA3 receptor or immunogenic fragment can be achieved, for polyclonal antibody production, using immunization protocols of conventional design, and any of a variety of mammalian hosts, such as sheep, goats and rabbits. Alternatively, for monoclonal antibody production, immunocytes such as splenocytes can be recovered from the immunized animal and fused, using hybridoma technology, to myeloma cells. The fusion products, i.e. hybridomas, are then screened by culturing in a selection medium, and cells producing antibody are recovered for continuous growth, and antibody recovery. Recovered antibody can then be coupled covalently to a reporter molecule, i.e.

a detectable label such as a radiolabel, enzyme label, luminescent label or the like, using linker technology established for this purpose, to form a specific probe for EAA3 receptors.

In detectably labelled form, e.g. radiolabelled form, DNA or RNA coding for the human EAA3 receptor, and selected regions thereof, may also be used, in accordance with another aspect of the present invention, as hybridization probes for example to identify sequence-related genes resident in the human or other mammalian genomes (or cDNA libraries) or to locate the EAA3-encoding DNA in a specimen, such as brain tissue. This can be done using either the intact coding region, or a fragment thereof having radiolabelled DNA e.g. ^{32}P , nucleotides incorporated therein. To identify the EAA3-encoding DNA in a specimen, it is desirable to use either the full length cDNA coding therefor, or a fragment which is unique thereto. With reference to Figure 1 and the nucleotide numbering appearing thereon, such nucleotide fragments include those comprising at least about 17 nucleic acids, and otherwise corresponding in sequence to a region coding for the N-terminus or C-terminus of the receptor, or representing a 5'-untranslated or 3'-untranslated region thereof. Examples of suitable nucleotide fragments for this purpose include nucleotides 426-446 and nucleotides 1251-1271 of EAA3a. These sequences, among others, as well as the intact gene itself, may also be used of course to clone EAA3-related human genes, particularly cDNA equivalents thereof, by standard

hybridization techniques.

Embodiments of the present invention are described in detail in the following non-limiting Examples.

Example 1 - Isolation of DNA coding for the human EAA3a receptor

cDNA coding for the human EAA3a receptor was identified by probing human fetal brain cDNA that was obtained as an EcoRI-based lambda phage library (lambda ZAP*) from Stratagene Cloning Systems (La Jolla, California, U.S.A.).

10 The cDNA library was screened using an oligonucleotide probe having the following specific sequence:

5'-ATCGGCGGCATCTTCATTGTTCTGGCTGCAGGACTCGTGC-3'

The fetal brain cDNA library was screened under the following hybridization conditions; 6xSSC, 25% formamide, 5x Denhardt's solution, 10mM Na₂HPO₄ buffer, 0.5% sodium pyrophosphate, 0.5% SDS, 100µg/ml denatured salmon sperm DNA, 42°C. Filters were washed with 6xSSC containing 0.5% SDS at 25°C for 5 minutes, followed by a 15 minute wash at 42°C with 2xSSC containing 0.5% SDS. The final wash was with 1xSSC
20 containing 0.5% SDS at 50°C for 15 minutes. Filters were exposed to X-ray film (Kodak*) overnight. Of 10⁶ clones screened, only two cDNA inserts were identified; one of about 0.9kb designated RKCSFG72, and another of about 2.7kb designated RKCS5F81. For sequencing, the '72 and '81 phages

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were plaque purified, then excised as phagemids according to the supplier's specifications, to generate insert-carrying Bluescript-SK* variants of the phagemid vectors. Sequencing of the '72 clone across its entire sequence revealed an open reading frame representing the C-terminal region but no putative termination codon. Sequencing across the '81 insert revealed a DNA sequence with about 80% identity with the '72 clone. The '81 clone displayed significant overlap to the '72 clone and included an additional 5' sequence.

10 Since no initiation and termination codons were apparent in the '72 sequence, the 5' and 3' regions of the '72 clone was sought. For this purpose, a 2.0kb EcoRI fragment representing the '81 clone and a 0.9kb EcoRI fragment representing the '72 clone were isolated, ³²P-labelled, and then used to re-screen the same fetal brain cDNA library under the following hybridization conditions: 6xSSC, 25% formamide, 5x Denhardt's solution, 0.5% SDS, 100µg/ml denatured salmon sperm DNA, 30°C. Filters were washed twice with 2xSSC containing 0.5% SDS at 25°C for 5 minutes, followed by a 15
20 minute final wash at 42°C with 2xSSC containing 0.5% SDS. Filters were exposed to X-ray film (Kodak*) overnight. Of 10⁶ clones screened, only two cDNA were identified, one of about 1.5kb designated RKCS221, and the other of about 1.8kb designated RKC41. Sequencing the entire '221 insert revealed more of the 5' sequence of the '72 clone as well as a

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termination codon and about 250 bases of the 3' non-coding region. Sequencing the entire '41 insert revealed more of the 5' sequence but still did not reveal an initiation codon.

Thus, the same fetal brain cDNA library was screened using an oligonucleotide probe (based on the '41 sequence) capable of annealing to the 5' region of the '41 sequence. The specific sequence of the ^{32}P -labelled probe is provided below:

5'-CCATCATTTGAGAAGTGGTCC-3'

10

This probe was ^{32}P -labelled and then used to re-screen the same fetal brain cDNA library under the following hybridization conditions: 6xSSC, 50% formamide, 5x Denhardt's solution, 0.5% SDS, 100 $\mu\text{g}/\text{ml}$ denatured salmon sperm DNA, 30 $^{\circ}\text{C}$. Filters were washed twice with 2xSSC containing 0.5% SDS at 25 $^{\circ}\text{C}$ for 5 minutes, following by a 15 minute final wash at 42 $^{\circ}\text{C}$ with 2xSSC containing 0.5% SDS. Filters were exposed to X-ray film (Kodak*) overnight. Of 10^6 clones screened, a single cDNA insert was identified of about 1.7kb designated RKS71. The '71 insert, when sequenced, revealed the initiation condon together with about 417 bases of 5' non-coding region and a significant overlap with the '41 insert.

20

To provide the entire coding region of the receptor, the strategy depicted in Figure 2 was then applied to generate the 6.3 kb phagemid pBS/humEAA3a which carries the intact EAA3a receptor-encoding DNA as a 3.3kb NotI/HindIII insert in

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a 3.0kb pBluescript phagemid background. Phagemid pBS/humEAA3a was deposited under the terms of the Budapest Treaty with the American Type Culture Collection in Rockville, Maryland USA on November 12, 1992, and has been assigned accession number ATCC 75350.

Example 2 - Construction of genetically engineered cells producing the human EAA3a receptor

For transient expression in mammalian cells, cDNA encoding the EAA3a receptor was incorporated into the mammalian expression vector pcDNAI/Amp (pcDNAIA), which is available commercially from Invitrogen Corporation (San Diego, California, USA; catalogue number V490-20), as depicted in Figure 3. pcDNAIA is a multifunctional 4.8 kb plasmid vector designed for cDNA expression in eukaryotic systems, and cDNA analysis in prokaryotes. Incorporated on the vector are the CMV promoter and enhancer, splice segment and polyadenylation signal, an SV40 and Polyoma virus origin of replication, M13 origin to rescue single strand DNA for sequencing and mutagenesis, Sp6 and T7 RNA promoters for the production of sense and anti-sense RNA transcripts and a Col E1-like high copy plasmid origin. A polylinker is located appropriately downstream of the CMV promoter and 3' of the T7 promoter.

Briefly, the EAA3a-encoding cDNA insert was released from pBS/humEAA3a as a 3.3kb NotI/NotI fragment subsequent to insertion of a HindIII/NotI adaptor at the 3' end of the insert. The 3.3 kb fragment was then incorporated at the NotI site in the pcDNAIA vector to form the expression vector

pcDNAIA/humEAA3a.

For transient expression of the EAA3a-encoding DNA, monkey-derived, fibroblast-like cells of the COS-1 lineage (available from the American Type Culture Collection, Rockville, Maryland as ATCC CRL 1650) were transfected with approximately 8ug DNA (as pcDNAIA/humEAA3a) per 10^6 COS cells, by DEAE-mediated DNA transfection and treated with chloroquine according to conventional procedures. Briefly, COS-1 cells were plated at a density of 5×10^6 cells/dish and then grown for 24 hours in FBS-supplemented DMEM/F12 medium. Medium was then removed and cells were washed with PBS and then with medium. There was then applied on the cells 10ml of a transfection solution containing DEAE dextran (0.4mg/ml), 100μM chloroquine, 10% NuSerum*, DNA (0.4mg/ml) in DMEM/F12 medium. After incubation for 3 hours at 37°C, cells were washed in PBS and medium as just described and then shocked for 1 minute with 10% DMSO in DMEM/F12 medium. Cells were allowed to grow for 2-3 days in 10% FBS-supplemented medium, and at the end of incubation dishes were placed on ice, the cells were washed with ice cold PBS and then removed by scraping. Cells were then harvested by centrifugation at 1000 rpm for 10 minutes and the cellular pellet was frozen in liquid nitrogen, for subsequent use in ligand binding assays. Northern blot analysis of a thawed aliquot of frozen cells confirmed expression of receptor-encoding cDNA in cells under storage.

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In a like manner, stably transfected cell lines can also be prepared using two different cell types as host: CHO K1 and CHO Pro5. To construct these cell lines, cDNA coding for human EAA3a is incorporated into the mammalian expression vector pRC/CMV (Invitrogen*), which enables stable expression. Insertion at this site places the cDNA under the expression control of the cytomegalovirus promoter and upstream of the polyadenylation site and terminator of the bovine growth hormone gene, and into a vector background comprising the
10 neomycin resistance gene (driven by the SV40 early promoter) as selectable marker.

To introduce plasmids constructed as described above, the host CHO cells are first seeded at a density of 5×10^5 in 10% FBS-supplemented α MEM medium. After growth for 24 hours, fresh medium is added to the plates and three hours later, the cells are transfected using the conventional calcium phosphate-DNA co-precipitation procedure. Briefly, 3 μ g of DNA is mixed and incubated with buffered calcium solution for 10 minutes at room temperature. An equal volume
20 of buffered phosphate solution is added and the suspension is incubated for 15 minutes at room temperature. Next, the incubated suspension is applied to the cells for 4 hours, removed and cells were shocked with medium containing 15% glycerol. Three minutes later, cells are washed with medium and incubated for 24 hours at normal growth conditions. Cells

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resistant to neomycin are selected in 10% FBS-supplemented alpha-MEM medium containing G418 (1mg/ml). Individual colonies of G418-resistant cells are isolated about 2-3 weeks later, clonally selected and then propagated for assay purposes.

Example 3 - Ligand binding assays

10 Transfected cells in the frozen state were resuspended in ice-cold distilled water using a hand homogenizer and centrifuged for 20 minutes at 50,000g. The supernatant was discarded and the membrane pellet stored frozen at -70°C .

COS cell membrane pellets were suspended in ice cold 50mM Tris-HCl (pH 7.55, 5°C) and centrifuged again at 50,000g for 10 minutes in order to remove endogenous glutamate that would compete for binding. Pellets were resuspended in ice cold 50mM Tris-HCl (pH 7.55) buffer and the resultant membrane preparation was used as tissue source for binding experiments described below. Proteins were determined using the Pierce Reagent* with BSA as standard.

20 Binding assays were then performed, using an amount of COS-derived membrane equivalent to 25-100ug as judged by protein determination and selected radiolabelled ligand. In particular, for kainate binding assays, incubation mixtures consisted of 25-100 μg tissue protein and [vinylidene- ^3H] kainic acid (58Ci/mmole, 80nM final) in the cold incubation

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buffer, 1ml final volume. Non-specific binding was in the presence of 1mM L-glutamate. Samples were incubated on ice for 60 minutes, and bound and free ligand were then separated by rapid filtration using a PHD cell harvester and GF/B filters pre-soaked in ice-cold 0.3% polyethyleneimine. Filters were washed twice in 4ml of the cold incubation buffer, then placed in scintillation vials with 5ml of Beckman Ready-Protein* Plus scintillation cocktail for counting.

10 For AMPA-binding assays, incubation mixtures consisted of 25-100ug tissue protein and D,L- α -[5-methyl-³H]amino-3-hydroxy-5-methylisoxazole-4-propionic acid (3H-AMPA, 27.6Ci/mmol, 10nM final) with 0.1M KSCN and 2.5mM CaCl₂ in the 1ml final volume. Non-specific binding was determined in the presence of 1mM L-glutamate. Samples were incubated on ice for 60 minutes in plastic minivials, and bound and free ligand were separated by centrifugation for 30 minutes at 50,000g. Pellets were washed twice in 4ml of the cold incubation buffer, then 5ml of Beckman Ready-Protein* Plus scintillation cocktail was added, for counting.

20 Scatchard analysis indicated that the recombinantly expressed human EAA3a receptor contains a single class of [³H]-labelled kainate binding sites with a dissociation constant (K_d) of about 129.3 $\pm$ 15.0 nM (Figure 5). Further, the maximum kainate-binding of the EAA3a receptor when expressed in COS cells has been found to be 1469 $\pm$ 909 fmol/mg

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protein.

[³H]-kainate displacement assays have also been performed for the EAA3a receptor in COS cells to determine the relative binding affinity of selected ligands. These results, as illustrated in Figure 6, indicate the rank order of potency of the ligands in displacing ³H-kainate binding to the EAA3a receptor to be as follows:

domoate>kainate>L-glutamate=quisqualate>DNQX=CNQX>AMPA>dihydrokainate>NMDA

Assays performed in this manner, using membrane preparations derived from the EAA3a-producing COS cells, revealed specific [³H]-kainate binding of 167 fmol/mg protein at 80nM, labelled ligand (Figure 4). Mock transfected cells exhibited no specific binding of any of the ligands tested. These results demonstrate clearly that the human EAA3a receptor is binding kainate specifically. This activity, coupled with the fact that there is little or no demonstrable binding of either AMPA or NMDA clearly assigns the EAA3a receptor to be of the kainate type of EAA receptor. Further, this binding profile indicates that the receptor is functioning in an authentic manner, and can therefore reliably predict the ligand binding "signature" of its non-recombinant counterpart from the intact human brain. These features make the recombinant receptor especially useful for selecting and characterizing ligand compounds which bind to the receptor, and/or for selecting and characterizing compounds which may act by displacing other ligands from the receptor. The isolation of the EAA3a receptor gene in a pure form, capable

of being expressed as a single, homogenous receptor species, therefore frees the ligand binding assay from the lack of precision introduced when complex, heterogeneous receptor preparations from human and non-human brains are used to attempt such characterizations.

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CLAIMS:

1. An isolated polynucleotide that codes for a human EAA3 receptor, selected from the group consisting of:

5 a) a human EAA3a receptor having the amino acid sequence shown in Figure 1,

b) a human EAA3b receptor having the amino acid sequence shown in Figure 1, with the exception that the aspartate residue at position 639 is an asparagine residue,

10 c) a human EAA3c receptor having the amino acid sequence of Figure 1, with the exception that 40 amino acids have been deleted from the C-terminus and amino acid residues 826 to 836 are as shown in Fig. 4B,

d) a human EAA3d receptor having the amino acid sequence of Figure 1, with the exception that amino acid
15 residues 6 to 61 are deleted, and

e) a human EAA3 receptor having an amino acid sequence having at least 97 percent sequence identity to the amino acid sequence of any one of (a), (b), (c) or (d).

2. The isolated polynucleotide according to claim 1,
20 that codes for the human EAA3a receptor.

3. The isolated polynucleotide according to claim 1, that codes for the human EAA3b receptor.

4. The isolated polynucleotide according to claim 1, that codes for the human EAA3c receptor.

25 5. A recombinant DNA construct having incorporated therein the polynucleotide as defined in any one of claims 1 to 4.

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6. The recombinant DNA construct according to claim 5, wherein said polynucleotide is linked operably with DNA enabling expression and secretion of said receptor in a cellular host.

5 7. An isolated protein selected from the group consisting of:

a) a human EAA3a receptor having the amino acid sequence shown in Figure 1,

10 b) a human EAA3b receptor having the amino acid sequence shown in Figure 1, with the exception that the aspartate residue at position 639 is an asparagine residue,

c) a human EAA3c receptor having the amino acid sequence of Figure 1, with the exception that 40 amino acids have been deleted from the C-terminus and amino acid
15 residues 826 to 836 are as shown in Fig. 4B,

d) a human EAA3d receptor having the amino acid sequence of Figure 1, with the exception that amino acid residues 6 to 61 are deleted, and

20 e) a human EAA3 receptor having an amino acid sequence having at least 97 percent sequence identity to the amino acid sequence of any one of (a), (b), (c) or (d).

8. An isolated human EAA3a receptor having the amino acid sequence shown in Figure 1.

9. An isolated human EAA3a receptor having an amino
25 acid sequence with at least 97 percent sequence identity to the isolated human EAA3a receptor defined in claim 8.

10. An isolated human EAA3b receptor having the amino acid sequence shown in Figure 1, with the exception that the aspartate residue at position 639 is an asparagine residue.

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11. An isolated human EAA3b receptor having an amino acid sequence with at least 97 percent sequence identity to the isolated human EAA3b receptor defined in claim 10.

12. An isolated human EAA3c receptor having the amino acid sequence of Figure 1, with the exception that 40 amino acids have been deleted from the C-terminus and amino acid residues 826 to 836 are as shown in Fig. 4B.

13. An isolated human EAA3c receptor having an amino acid sequence with at least 97 percent sequence identity to the isolated human EAA3c receptor defined in claim 12.

14. An isolated human EAA3d receptor having the amino acid sequence of Figure 1, with the exception that amino acid residues 6 to 61 are deleted.

15. An isolated human EAA3d receptor having an amino acid sequence with at least 97 percent sequence identity to the isolated human EAA3d receptor defined in claim 14.

16. A kainate-binding fragment of the protein as defined in claim 7, wherein said kainate-binding fragment is unique to said human EAA3 receptor.

17. A polyclonal antibody which binds the protein as defined in claim 7.

18. An antibody which binds the protein as defined in claim 7.

19. An immunogenic fragment of the protein as defined in claim 7, wherein said immunogenic fragment is unique to said EAA3 receptor.

20. A cell that has been engineered genetically to produce a kainate-binding human EAA receptor, said cell having incorporated expressibly therein a heterologous

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polynucleotide wherein the heterologous polynucleotide is the polynucleotide defined in any one of claims 1 to 4.

21. The cell according to claim 20, which is a mammalian cell.

5 22. A membrane preparation derived from the cell as defined in claim 21, wherein said membrane preparation comprises the protein as defined in claim 7, or the receptor as defined in any one of claims 8 to 15, or the fragment as defined in claim 16.

10 23. A process for obtaining a substantially homogeneous source of a human EAA receptor, which comprises the steps of culturing cells having incorporated expressibly therein the polynucleotide as defined in any one of claims 1 to 4, and then recovering the EAA3 receptor from
15 the cultured cells.

24. The process for obtaining a substantially homogeneous source of a human EAA receptor according to claim 23, comprising the step of obtaining a membrane preparation from the cultured cells and then recovering the
20 EAA3 receptor from the membrane preparation.

25. A method of assaying a test ligand for interaction with a human CNS receptor, which comprises the steps of incubating the test ligand under appropriate conditions with the human EAA receptor-producing cell as defined in
25 claim 20 or 21, or with the membrane preparation as defined in claim 22, and then determining one of the extent of binding between the human EAA3 receptor and the test ligand, or the ligand-induced electrical current across said cell or membrane.

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FIGURE 1

	1	GAATTC	CGTCTT	CTTTCCCC	CTTTCCCT	CCTCTGT	CTGTGCCT	ATCCCC	CGACTTTT	TGC		
	1	-----	-----	-----	-----	-----	-----	-----	-----	-----	60	
		CTTAAG	GCAGAAG	AAAGGG	GAAAGG	GAGGAG	ACAGAC	ACGGAT	AGGGGG	GCTGAA	ACG	
	61	ATCTGA	CCAAAG	GACGAAT	GAGGGAG	ACGTTCC	TGCAGAT	CGGGGC	CAGCAACT	TTTCCT	CA	
	61	-----	-----	-----	-----	-----	-----	-----	-----	-----	120	
		TAGACT	GGTTTC	CTGCTT	ACTCCCT	CTGCAAG	GACGTCT	AGCCCC	CGTCGTT	GAAAGG	AGT	
	121	GCTGGT	CTCTGG	GCTCCG	GAGCCAG	AGAGCG	CTGATCCT	CCGCGT	CTGCGG	CCCCAT	GAAG	
	121	-----	-----	-----	-----	-----	-----	-----	-----	-----	180	
		CGACC	AGAGAC	CCCGAG	GCCTCG	GTCTCT	CGCGACT	AGGAGG	CGCAGAC	CGCCGG	TACTTC	
	181	AGAGAG	AGAGCC	GTGATG	GGGCTAG	CGACAG	CACTGAG	GAGCCCC	GAGAGAG	CTCAGC	CTT	
	181	-----	-----	-----	-----	-----	-----	-----	-----	-----	240	
		TCTCT	CTCTCG	GCACTA	CCCGAT	CGCTGTC	GTGACTC	CTCGGG	GCTCTCT	CGAGTC	GGAA	
	241	GCCAGC	CAGCTCC	GCGGTCC	CACGCG	GGTTCCT	CGAGCTC	GCTCCG	TGGGGAG	CGCGCA		
	241	-----	-----	-----	-----	-----	-----	-----	-----	-----	300	
		CGGT	CGGTCG	AGGCGC	CAGGGT	GCGCCCA	AGGGAG	CTCGAG	CGAGGC	ACCCCT	CGCGCGT	
	301	GCGTG	CTTGGA	ACCGG	AGCATCC	AGAGAG	GATGAGG	CGGGGAC	CCCGGCC	CAAGTT	GGGTG	
	301	-----	-----	-----	-----	-----	-----	-----	-----	-----	360	
		CGCAC	GAACCT	TGGCCT	CGTAGG	TCTCTC	CTACTCC	GCCCCCT	TGGGCC	GGGTTC	AAACCC	CAC
	361	CATCT	CTCGGG	CGTCCG	GCAGCG	GGCTGT	ATCTCG	GCATGA	ATTAAGA	AGCTAG	GGAAG	ATG
	361	-----	-----	-----	-----	-----	-----	-----	-----	-----	420	
		GTAGA	GAGCCC	GCAGGC	CGTCG	CCGACAT	AGACCG	TACTTA	ATTCTT	CGATC	CTTCT	AC
												M
												-30
	421	GAGCAC	GGCACAC	TCTCTC	GCCCAG	CCCCGG	GCTCTGG	ACCAGG	GACACC	AGCTGG	GGCACTC	
	421	-----	-----	-----	-----	-----	-----	-----	-----	-----	480	
		CTCGT	GCCGTG	TGAGG	AGCGGG	TGCGGG	CCCCG	AGACCT	GGTCCCT	GTGGT	CGACCC	GTGAG
	-29	E	H	G	T	L	L	A	Q	P	G	L
	-29											W
												T
												R
												D
												T
												S
												W
												A
												L
	481	CTCTA	TTTCCT	CTGCTA	TATCCT	CCCTC	AGACCG	CCCCG	CAAGT	ACTCAG	GATCGG	AGGG
	481	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	540
		GAGAT	AAAGG	AGACG	ATATAG	GAGGG	AGTCTG	GCGGG	GCGTTC	ATGAGT	CCTAGC	CTCCC
	-09	L	Y	F	L	C	Y	I	L	P	Q	T
												A

|_ Mature Amino-Terminal

	ATTTTGGAAACAGTGGA	AATGAGCCTGTTAATGTTGAAGAATTAGCTTTCAAGTTTGCA	
541	-----+-----+-----+-----+-----+-----+-----+-----+		600
	TAAAAACTTTGT	CACCTTTTACTCGGACAATTACA	ACTTCTTAATCGAAAGTTCAAACGT
12	I F E T V E N E P V N V E E L A F K F A		31
	GTCACCAGCATTAACAGAAACCGAACCCTGATGCCTAACACCACATTAACCTATGACATC		
601	-----+-----+-----+-----+-----+-----+-----+-----+		660
	CAGTGGT	CGTAATTGTCTTTGGCCTTGGGACTACGGATTGTGGTGTAATTGGATACTGTAG	
32	V T S I N R N R T L M P N T T L T Y D I		51
	CAGAGAATTAACCTTTTTGATAGTTTTGAAGCCTCGCGGAGAGCATGTGACCAGCTGGCT		
661	-----+-----+-----+-----+-----+-----+-----+-----+		720
	GTCTCTTAATTGGAAAACTATCAAAACTTCGGAGCGCCTCTCGTACACTGGTCGACCGA		
52	Q R I N L F D S F E A S R R A C D Q L A		71
	CTTGGTGTGGCTGCTCTCTTTGGCCCTTCCCATAGCTCCTCCGTCAGTGCTGTGCAGTCT		
721	-----+-----+-----+-----+-----+-----+-----+-----+		780
	GAACCACACCGACGAGAGAAACCGGGAAGGGTATCGAGGAGGCAGTCACGACACGTCAGA		
72	L G V A A L F G P S H S S S V S A V Q S		91

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781	ATTGCAATGCTCTCGAAGTTCCACACATACAGACCCGCTGGAAACACCCCTCGGTGGAC	840
92	TAAACGTTACGAGAGCTTCAAGGTGTGTATGTCTGGGCGACCTTTGTGGGGAGCCACCTG	111
	I C N A L E V P H I Q T R W K H P S V D	
841	AACAAAGATTTGTTTTACATCAACCTTTACCCAGATTATGCAGCTATCAGCAGGGCGATC	900
112	TTGTTTCTAAACAAAATGTAGTTGGAAATGGGTCTAATACGTCGATAGTCGTCCTCGCTAG	130
	N K D L F Y I N L Y P D Y A A I S R A I	
901	CTGGATCTGGTCCTCTATTACAACCTGGAAAACAGTGACAGTGGTGTATGAAGACAGCACA	960
132	GACCTAGACCAGGAGATAATGTTGACCTTTTGTCACTGTCACCACATACTTCTGTCGTGT	150
	L D L V L Y Y N W K T V T V V Y E D S T	
961	GGTCTAATTCGTCTACAAGAGCTCATCAAAGCTCCCTCCAGATATAATATTAATAATCAAA	1020
152	CCAGATTAAGCAGATGTTCTCGAGTAGTTTCGAGGGAGGTCTATATTATAATTTTAGTTT	170
	G L I R L Q E L I K A P S R Y N I K I K	
1021	ATCCGCCAGCTGCCCTCTGGGAATAAAGATGCCAAGCCTTTACTCAAGGAGATGAAGAAA	1080
172	TAGGCGGTTCGACGGGAGACCCTTATTTCTACGGTTCGGAAATGAGTTCCTCTACTTCTTT	190
	I R Q L P S G N K D A K P L L K E M K K	
1081	GGCAAGGAGTTCTATGTGATATTTGATTGTTTACATGAAACAGCCGCTGAAATCCTTAAG	1140
192	CCGTTCTCAAGATACTATAAACTAACAAGTGTACTTTGTTCGGCGACTTTAGGAATTC	211
	G K E F Y V I F D C S H E T A A E I L K	
1141	CAGATTCTGTTTCATGGGCATGATGACCGAATACTATCACTACTTTTTTACCAACCCTGGAC	1200
212	GTCTAAGACAAGTACCCGTACTACTGGCTTATGATAGTGATGAAAAGTGTTGGGACCTG	231
	Q I L F M G M M T E Y Y H Y F F T T L D	
1201	TTATTTGCTTTGGATCTGGAACCTCTATAGGTACAGTGGCGTAAACATGACCGGGTTTgGG	1260
232	AATAAACGAAACCTAGACCTTGAGATATCCATGTCACCGCATTTGTACTGGCCCAAACCC	251
	L F A L D L E L Y R Y S G V N M T G F G	
1261	CTGCTTAACATTGACAACCCTCACGTGTCATCCATCATTGAGAAGTGGTCCATGGAGAGA	1320
252	GACGAATTGTAAGTGTGGGAGTGCACAGTAGGTAGTAAGTCTTCACCAGGTACCTCTCT	271
	L L N I D N P H V S S I I E K W S M E R	
1321	CTGCAGGCCCCACCCAGGCCCCGAGACTGGCCTTTTGGATGGCATGATGACAACCTGAAGCG	1380
272	GACGTCCGGGGTGGGTCCGGGCTCTGACCGGAAAACCTACCGTACTACTGTTGACTTCGC	291
	L Q A P P R P E T G L L D G M M T T E A	
1381	GCTCTGATGTACGATGCTGTGTACATGGTGGCCATTGCCTCGCACCGGGCATCCCAGCTG	1440
292	CGAGACTACATGCTACGACACATGTACCACCGGTAACGGAGCGTGGCCCGTAGGGTCGAC	311
	A L M Y D A V Y M V A I A S H R A S Q L	
1441	ACCGTCAGCTCCCTGCAGTGCCATAGACATAAGCCATGGCGCCTCGGACCCAGATTTATG	1500
312	TGGCAGTCGAGGGACGTCACGGTATCTGTATTCGGTACCGCGGAGCCTGGGTCTAAATAC	331
	T V S S L Q C H R H K P W R L G P R F M	

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FIG. 1 - page 3

1501	AACCTGATCAAAGAGGCCCGGTGGGATGGCTTGACTGGGCATATCACCTTTAATAAAACC	1560
332	TTGGACTAGTTTCTCCGGGCCACCCTACCGAACTGACCCGTATAGTGGAATTATTTTGG	351
	N L I K E A R W D G L T G H I T F N K T	
1561	AATGGCTTGAGGAAGGATTTTGATCTGGACATTATTAGTCTCAAAGAGGAAGGAACTGAA	1620
352	TTACCGAACTCCTTCCTAAAACTAGACCTGTAATAATCAGAGTTTCTCCTTCCTTGACTT	371
	N G L R K D F D L D I I S L K E E G T E	
1621	AAGATTGGGATTTGGAATTCCAACAGTGGGCTTAACATGACGGACAGCAACAAAGACAAG	1680
372	TTCTAACCTTAAACCTTAAGGTTGTCACCCGAATTGTACTGCCTGTCGTTGTTTCTGTTC	391
	K I G I W N S N S G L N M T D S N K D K	
1681	TCCAGCAATATCACTGATTTCATTGGCCAACAGAACACTCATTGTCACCACCATTCTGGAA	1740
392	AGGTCGTTATAGTGACTAAGTAACCGGTTGTCTTGTGAGTAACAGTGGTGGTAAGACCTT	411
	S S N I T D S L A N R T L I V T T I L E	
1741	GAACCCTATGTTATGTACAGGAAATCTGATAAGCCTCTATATGGAAATGACAGATTTGAA	1800
412	CTTGGGATACAATACATGTCCTTTAGACTATTTCGGAGATATACCTTTACTGTCTAAACTT	431
	E P Y V M Y R K S D K P L Y G N D R F E	
1801	GGATATTGCCTAGACCTGTTGAAAGAATTGTCAAACATCCTGGGTTTCATTTATGATGTT	1860
432	CCTATAACGGATCTGGACAACCTTCTTAACAGTTTGTAGGACCCAAAGTAAATACTACAA	451
	G Y C L D L L K E L S N I L G F I Y D V	
1861	AAACTAGTTCCCGATGGCAAATATGGGGCCCAGAATGACAAAGGGGAGTGGAACGGGATG	1920
452	TTTGATCAAGGGCTACCGTTTATACCCCGGGTCTTACTGTTTCCCCTCACCTTGCCCTAC	471
	K L V P D G K Y G A Q N D K G E W N G M	
1921	GTAAAGAACTCATAGATCACAGGGCTGACCTGGCAGTGGCTCCTCTTACCATCACCTAC	1980
472	CAATTTCTTGAGTATCTAGTGTCGCGACTGGACCGTCACCGAGGAGAATGGTAGTGGATG	491
	V K E L I D H R A D L A V A P L T I T Y	
1981	GTGCGGGAGAAAGTCATTGACTTCTCCAAACCCTTCATGACCCTAGGCATCAGCATTCTC	2040
492	CACGCCCTCTTTCAGTAACTGAAGAGGTTTGGGAAGTACTGGGATCCGTAGTCGTAAGAG	511
	V R E K V I D F S K P F M T L G I S I L	
2041	TACCGGAAGCCCAATGGTACCAATCCAGGCGTTTTCTCCTTCCTCAACCCCTGTCTCCA	2100
512	ATGGCCTTCGGGTTACCATGGTTAGGTCCGCAAAAGAGGAAGGAGTTGGGGGACAGAGGT	531
	Y R K P N G T N P G V F S F L N P L S P	
2101	GATATTTGGATGTATGTGCTCTTAGCCTGCTTGGGAGTCAGCTGTGTACTCTTTGTGATT	2160
532	CTATAAACCTACATACACGAGAATCGGACGAACCCTCAGTCGACACATGAGAAACACTAA	551
	D I W M Y V L L A C L G V S C V L F V I	
2161	GCAAGGTTTACACCCTACGAGTGGTATAACCCCCACCCATGCAACCCTGACTCAGACGTg	2220
552	CGTTCCAAATGTGGGATGCTCACCATATTGGGGGTGGGTACGTTGGGACTGAGTCTGCAC	571
	A R F T P Y E W Y N P H P C N P D S D V	

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FIG. 1 - page 4

	GTGGAAAACAATTTTACTTTACTAAATAGTTTTCTGGTTTGAGGCTCCTCATGCAG	
2221	-----+-----+-----+-----+-----+-----+-----+	2280
	CACCTTTTGTATAAATGAATGATTATCAAAGACCACCACTCAACCTCGAGAGTACGTC	
572	V E N N F T L L N S F W F G V G A L M Q	591
	CAAGGATCAGAGCTGATGCCCAAAGCTCTATCGACCAGAATAGTTGGAGGGATATGGTGG	
2281	-----+-----+-----+-----+-----+-----+-----+	2340
	GTTCCTAGTCTCGACTACGGGTTTCGAGATAGCTGGTCTTATCAACCTCCCTATACCACC	
592	Q G S E L M P K A L S T R I V G G I W W	611
	TTTTTCACCCTAATCATCATTTTCATCCTACACGGCCAATCTGGCTGCCTTCTTGACAGTA	
2341	-----+-----+-----+-----+-----+-----+-----+	2400
	AAAAAGTGGGATTAGTAGTAAGTAGGATGTGCCGGTTAGACCGACGGAAGAAGTGTGAT	
612	F F T L I I I S S Y T A N L A A F L T V	631
	GAGAGAATGGAATCCCCCATAGATTCCGGCAGATGATCTGGCAAAGCAAACCAAGATAGAA	
2401	-----+-----+-----+-----+-----+-----+-----+	2460
	CTCTCTTACCTTAGGGGGTATCTAAGCCGTCTACTAGACCGTTTCGTTTGGTTCTATCTT	
632	E R M E S P I D S A D D L A K Q T K I E	651
	TATGGGGCGGTTAGAGATGGATCAACAATGACCTTCTTCAAGAAATCAAAAATCTCCACC	
2461	-----+-----+-----+-----+-----+-----+-----+	2520
	ATACCCCGCCAATCTCTACCTAGTTGTTACTGGAAGAAGTCTTTAGTTTTTAGAGGTGG	
652	Y G A V R D G S T M T F F K K S K I S T	671
	TATGAGAAGATGTGGGCTTTCATGAGCAGCAGGCAGCACCGCCCTGGTAAGAAACAGT	
2521	-----+-----+-----+-----+-----+-----+-----+	2580
	ATACTCTTCTACACCCGAAAGTACTCGTCGTCGTCGTCGTCGGCGGGACCATTCTTTGTCA	
672	Y E K M W A F M S S R Q Q T A L V R N S	691
	GATGAGGGGATCCAGAGAGTGCTCACCACAGACTACGCGCTGCTGATGGAGTCCACCAGC	
2581	-----+-----+-----+-----+-----+-----+-----+	2640
	CTACTCCCCTAGGTCTCTCACGAGTGGTGTCTGATGCGCGACGACTACCTCAGGTGGTCG	
692	D E G I Q R V L T T D Y A L L M E S T S	711
	ATTGAGTATGTGACGCAGAGAACTGCAACCTCACTCAGATCGGGGGCCTCATTGACTCC	
2641	-----+-----+-----+-----+-----+-----+-----+	2700
	TAACCTCATACTGCGTCTCTTTGACGTTGGAGTGAGTCTAGCCCCCGGAGTAAGTGGG	
712	I E Y V T Q R N C N L T Q I G G L I D S	731
	AAAGGTACGGAGTGGGAACACCTATTGGTTCTCCTTACCGGGATAAAATTACTATTGCT	
2701	-----+-----+-----+-----+-----+-----+-----+	2760
	TTTCCAATGCCTCACCCTTGTGGATAACCAAGAGGAATGGCCCTATTTTAATGATAACGA	
732	K G Y G V G T P I G S P Y R D K I T I A	751
	ATTCTTCAACTCCAAGAAGAAGGAAGCTGCATATGATGAAAGAGAAGTGGTGGCGTGGG	
2761	-----+-----+-----+-----+-----+-----+-----+	2820
	TAAGAAGTTGAGGTTCTTCTTCCCTTCGACGTATACTACTTTCTCTTCACCACCGCACCC	
752	I L Q L Q E E G K L H M M K E K W W R G	771
	AATGGCTGCCCCGAGGAAGACAACAAGAAGCCAGTGCCCTGGGAGTGGAATAATTGGA	
2821	-----+-----+-----+-----+-----+-----+-----+	2880
	TTACCGACGGGGCTCCTTCTGTTGTTTCTTCGGTCACGGGACCCTCACCTTTTATAACCT	
772	N G C P E E D N K E A S A L G V E N I G	791
	GGCATCTTCATTGTTCTGGCTGCCGGACTGGTCCTTTCTGTATTTGTAGCTATTGGAGAA	
2881	-----+-----+-----+-----+-----+-----+-----+	2940
	CCGTAGAAGTAACAAGACCGACGGCCTGACCAGGAAGACATAAACATCGATAACCTCTT	
792	G I F I V L A A G L V L S V F V A I G E	811

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FIG. 1 - page 5

2941 TTCATATACAAATCACGGAAGAATAATGATATTGAACAGTGTCTCTCTTTCAACGCTATC
 -----+-----+-----+-----+-----+-----+-----+
 812 AAGTATATGTTTAGTGCCTTCTTATTACTATAACTTGTCACAGAGAGAAAGTTGCGATAG
 F I Y K S R K N N D I E Q C L S F N A I 831

 3001 ATGGAAGAACTGGGAATCTCACTGAAGAATCAGAAAAAATAAAGAAAAAGTCAAGAACT
 -----+-----+-----+-----+-----+-----+-----+
 832 TACCTTCTTGACCCTTAGAGTGACTTCTTAGTCTTTTTTTATTTCTTTTTCAGTTCTTGA
 M E E L G I S L K N Q K K I K K K S R T 851

 3061 AAGGGGAAATCTTCCTTCACAAGTATCCTTACTTGTCATCAGAGACGAACTCAGAGAAAA
 -----+-----+-----+-----+-----+-----+-----+
 852 TTCCCCTTTAGAAGGAAGTGTTTCATAGGAATGAACAGTAGTCTCTGCTTGAGTCTCTTTT
 K G K S S F T S I L T C H Q R R T Q R K 871

 3121 GAGACTGTGGCGTGATCCAAGGAAACGCCTGTAGGAAGAAAAAGGATGCATTCCCTACAG
 -----+-----+-----+-----+-----+-----+-----+
 872 CTCTGACACCGCACTAGGTTCTTTGCGGACATCCTTCTTTTTTCTACGTAAGGGATGTC
 E T V A 875

 3181 ATTTTTGGAGAAAGGATTTCTGAGGAGTTGTGTGATGTGTTTCCATATATCTATATCCAT
 -----+-----+-----+-----+-----+-----+-----+
 TAAAAACCTCTTTCCTAAAGACTCCTCAACACACTACACAAAGGTATATAGATATAGGTA 3240

 3241 AACTCTGATTATGAATACAGATATAAGAAATACAAAAGTTTAAAAAGCTCACATAGATAT
 -----+-----+-----+-----+-----+-----+-----+
 TTGAGACTAATACTTATGTCTATATTCTTTATGTTTTCAAATTTTTCGAGTGTATCTATA 3300

 3301 GACTTGGGAAGTGACACCAGTTCTTTTAAAATAAATTTGTATGCACAAAAA
 -----+-----+-----+-----+-----+-----+-----+
 CTGAACCCTTCACTGTGGTCAAGAAAATTTTATTTAAACATACGTGTTTTTTTTTTTTTTT 3360

 EcoRI
 |
 3361 AAAAAAAAAAAAAAAAAAAGGAATTC 3385
 -----+-----+-----+-----+-----+-----+-----+
 TTTTTTTTTTTTTTTTTTTCCTTAAG

Figure 2

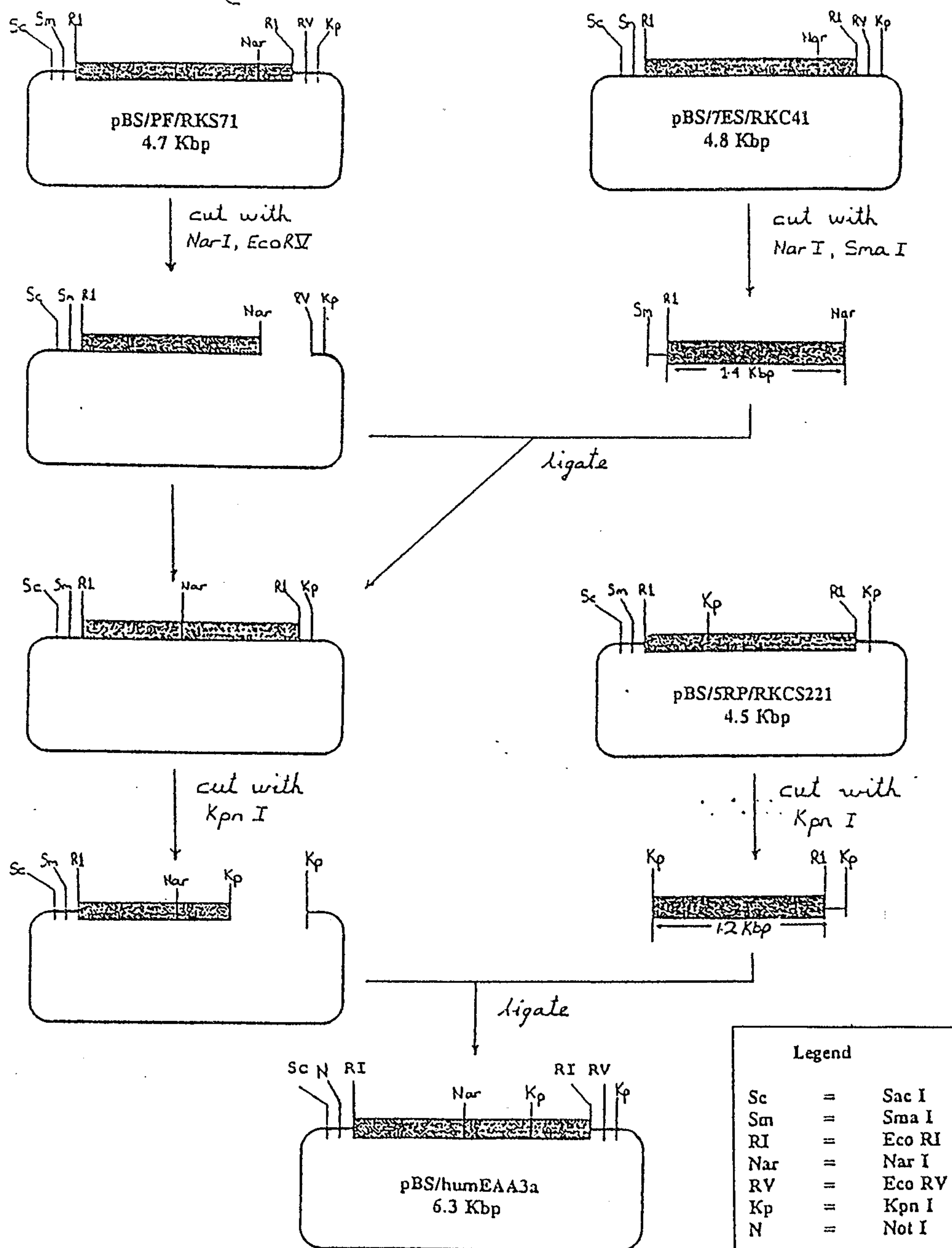
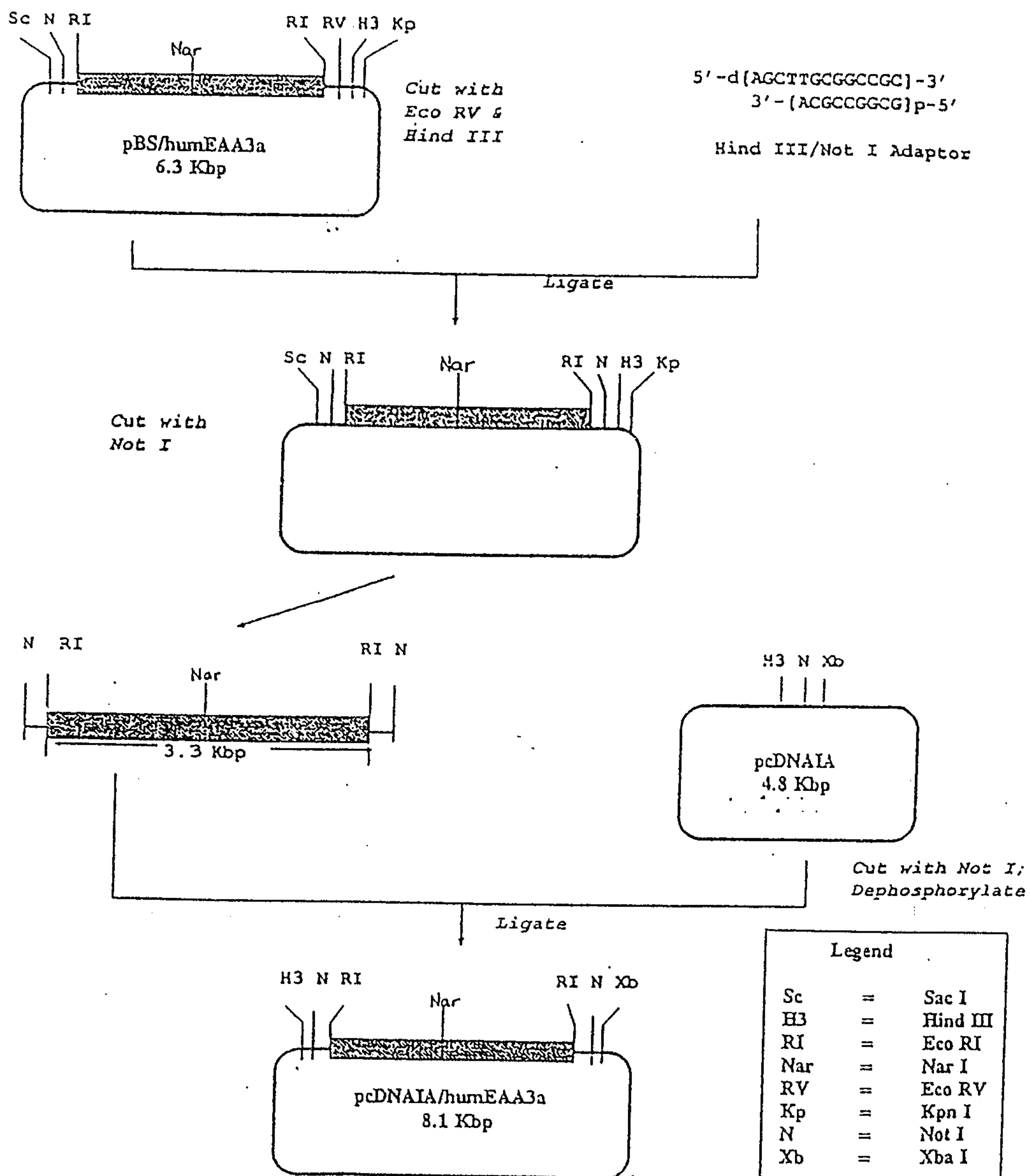


Figure 3



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AMINO ACID SEQUENCE:

NUCEOTIDE SEQUENCE:

FIGURE 4B

AMINO ACID SEQUENCE:

NUCLEOTIDE SEQUENCE:

FIGURE 4C

AMINO ACID SEQUENCE:

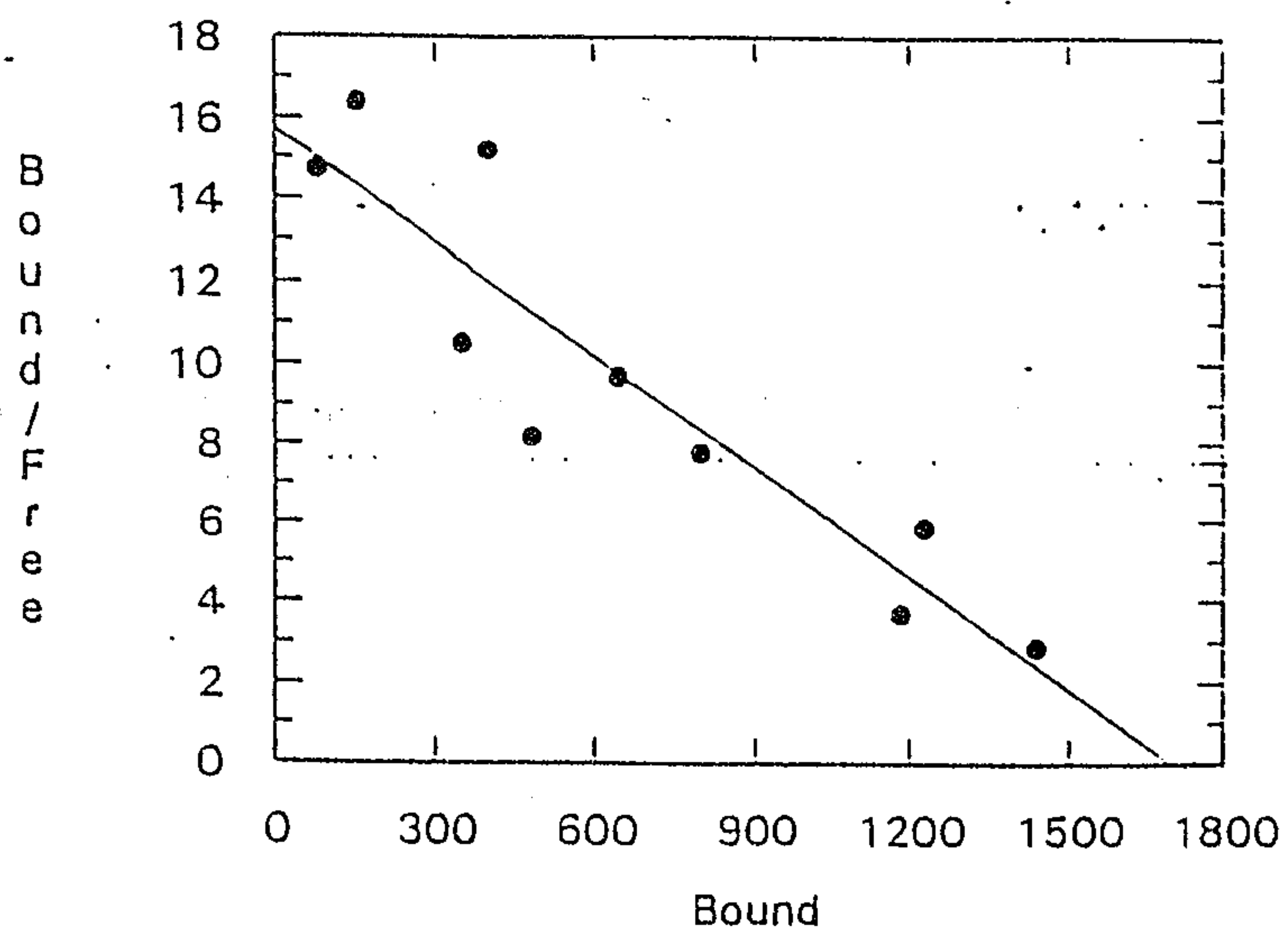
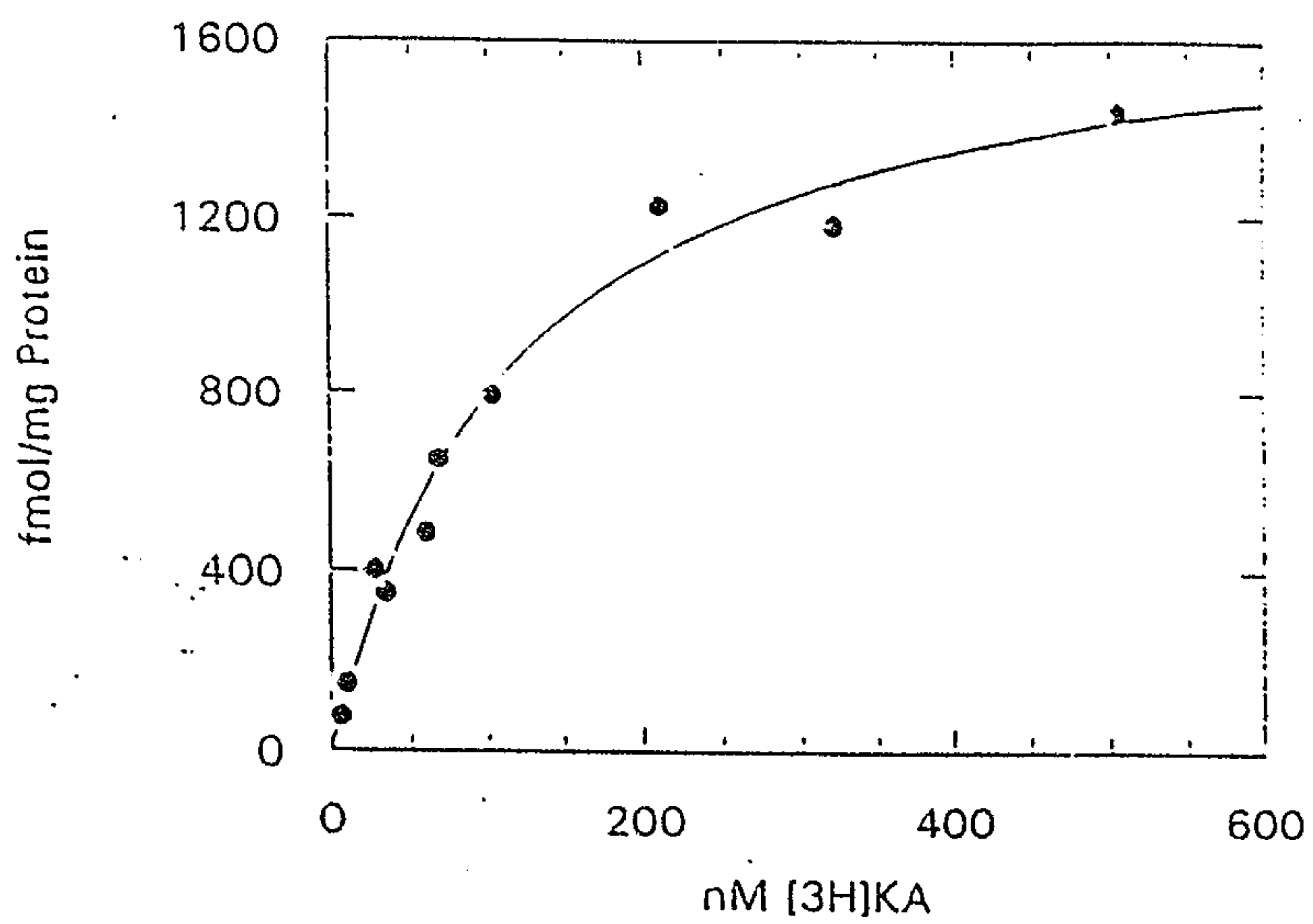
NUCLEOTIDE SEQUENCE:

HumEAA3d 536 GCATGTGACCAGCTGGCTCTTGGTGTGGCTGCTCTCTTTGGCCCTT 581
|||||
HumEAA3a 700 GAGAGCATGTGACCAGCTGGCTCTTGGTGTGGCTGCTCTCTTTGGCCCTT 749

Robert A. ...
G. ...

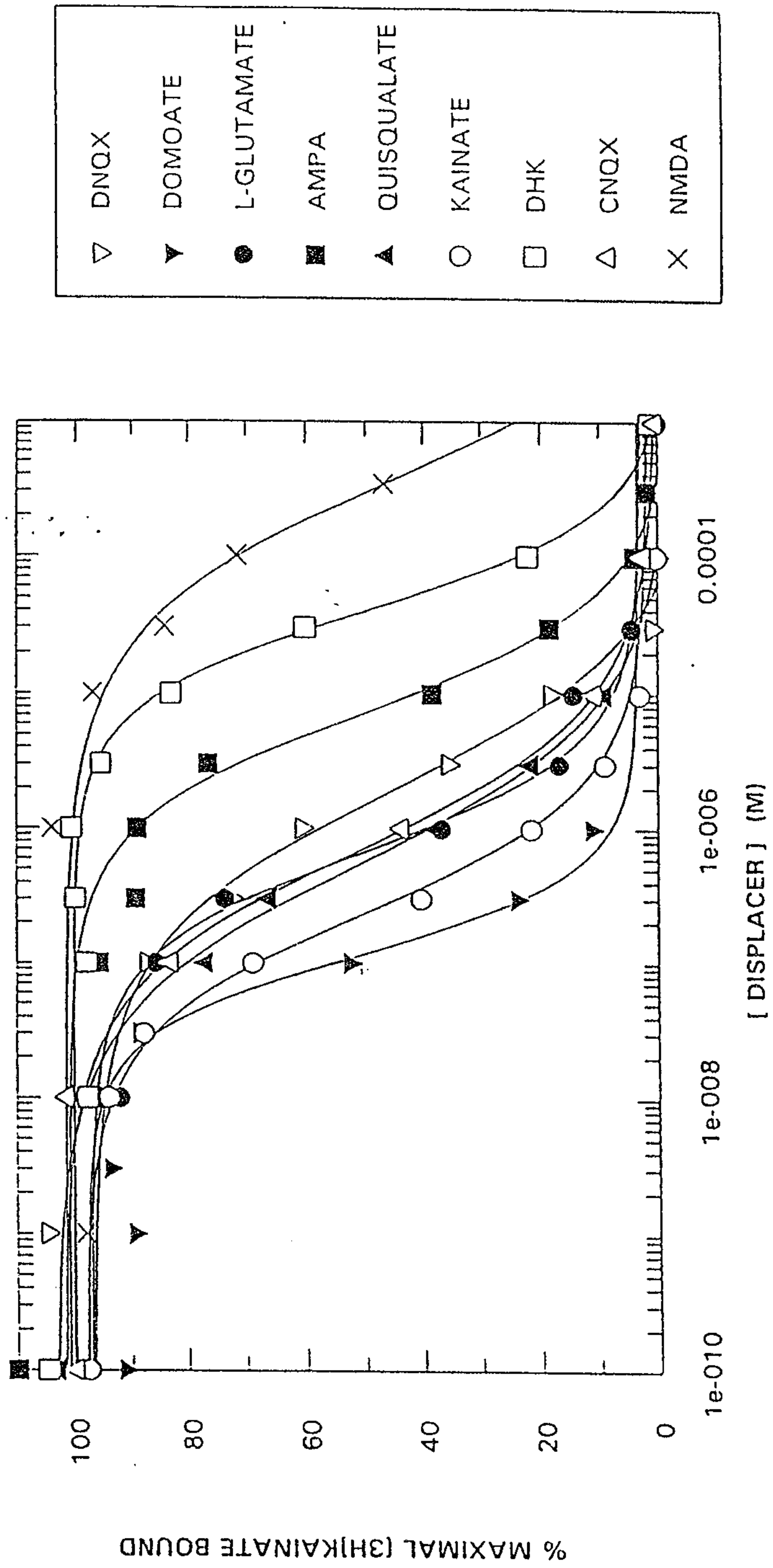
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Figure 5



Robert J. ...
...

Figure 6



Point A
Slope of line