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<p>(54) Title: NUCLEIC ACID SEQUENCES ENCODING CAPSAICIN RECEPTOR AND CAPSAICIN RECEPTOR-RELATED POLYPEPTIDES AND USES THEREOF</p>			
<p>(57) Abstract</p> <p>The present invention features vanilloid receptor polypeptides and vanilloid receptor-related polypeptides, specifically the capsaicin receptor subtypes VR1 and VR2 (VRRP-1), as well as the encoding polynucleotide sequences. In related aspects the invention features expression vectors and host cells comprising such polynucleotides. In other related aspects, the invention features transgenic animals having altered capsaicin receptor expression, due to, for example, the presence of an exogenous wild-type or modified capsaicin receptor-encoding polynucleotide sequence. The present invention also relates to antibodies that bind specifically to a capsaicin receptor polypeptide, and methods for producing these polypeptides. Further, the invention provides methods for using capsaicin receptor, including methods for screening candidate agents for activity as agonists or antagonists of capsaicin receptor activity, as well as assays to determine the amount of a capsaicin receptor-activating agent in a sample. In other related aspects, the invention provides methods for the use of the capsaicin receptor for the diagnosis and treatment of human disease and painful syndromes.</p>			

NUCLEIC ACID SEQUENCES ENCODING CAPSAICIN RECEPTOR AND CAPSAICIN
RECEPTOR-RELATED POLYPEPTIDES AND USES THEREOF

FIELD OF THE INVENTION

5 The present invention relates to nucleic acid and amino acid sequences encoding a receptor for vanilloid compound and polypeptides related to such vanilloid compound receptors, and to the use of these sequences in the diagnosis, study, and treatment of disease.

BACKGROUND OF THE INVENTION

10 Pain is initiated when the peripheral terminals of a particular group of sensory neurons, called nociceptors, are activated by noxious chemical, mechanical, or thermal stimuli. These neurons, whose cell bodies are located in various sensory ganglia, transmit information regarding tissue damage to pain processing centers in the spinal cord and brain (Fields Pain (McGraw-Hill, New York, 1987)). Nociceptors are characterized, in part, by their sensitivity to capsaicin, a natural product of capsicum 15 peppers that is the active ingredient of many "hot" and spicy foods. In mammals, exposure of nociceptor terminals to capsaicin leads initially to the perception of pain and the local release of neurotransmitters. With prolonged exposure, these terminals become insensitive to capsaicin, as well as to other noxious stimuli (Szolcsanyi in Capsaicin in the Study of Pain (ed. Wood) pgs. 255-272 (Academic Press, London, 1993)). This latter phenomenon of nociceptor desensitization underlies the seemingly 20 paradoxical use of capsaicin as an analgesic agent in the treatment of painful disorders ranging from viral and diabetic neuropathies to rheumatoid arthritis (Campbell in Capsaicin and the Study of Pain (ed. Wood) pgs. 255-272 (Academic Press, London, 1993); Szallasi et al. 1996 Pain 68:195-208). While some of this decreased sensitivity to noxious stimuli may reflect reversible changes in the nociceptor, such as depletion of inflammatory mediators, the long-term loss of responsiveness can be explained 25 by death of the nociceptor or destruction of its peripheral terminals following capsaicin exposure (Jancso et al. 1977 Nature 270:741-743; Szolcsanyi, *supra*).

Responsivity to capsaicin has been used to define sensory afferent fibers that transmit signals in response to noxious stimuli (chemical, thermal, and mechanical stimuli); however, the precise mechanism of action has remained unclear. Electrophysiological (Bevan et al. 1990 Trends Pharmacol. 30 Sci 11:330-333; Oh et al. 1996 J. Neuroscience 16:1659-1667) and biochemical (Wood et al. 1988 J. Neuroscience 8:3208-3220) studies have clearly shown that capsaicin excites nociceptors by increasing plasma membrane conductance through formation or activation of nonselective cation channels. While the hydrophobic nature of capsaicin has made it difficult to rule out the possibility that its actions are mediated by direct perturbation of membrane lipids (Feigin et al. 1995 Neuroreport 6:2134-2136), it has 35 been generally accepted that this compound acts at a specific receptor site on or within sensory neurons due to observations that capsaicin derivatives show structure-function relationships and evoke dose-dependent responses (Szolcsanyi et al. 1975 Drug. Res. 25:1877-1881; Szolcsanyi et al. 1976 Drug Res. 26:33-37)). The development of capsazepine, a competitive capsaicin antagonist (Bevan

et al. 1992 Br. J. Pharmacol. 107:544-552) and the discovery of resiniferatoxin, an ultrapotent capsaicin analogue from *Euphorbia* plants that mimics the cellular actions of capsaicin (deVries et al. 1989 Life Sci. 44:711-715; Szallasi et al. 1989 Neuroscience 30:515-520) further suggest that the capsaicin mediates its effects through a receptor. The nanomolar potency of resiniferatoxin has facilitated its use 5 as a high affinity radioligand to visualize saturable, capsaicin- and capsazepine-sensitive binding sites on nociceptors (Szallasi 1994 Gen. Pharmac. 25:223-243). Because a vanilloid moiety constitutes an essential structural component of capsaicin and resiniferatoxin, the proposed site of action of these compounds has been more generally referred to as the vanilloid receptor (Szallasi 1994 *supra*). The 10 action of capsaicin, resiniferatoxin, and the antagonist capsazepine have been well characterized physiologically using primary neuronal cultures (see, e.g., Szolcsanyi, "Actions of Capsaicin on Sensory 15 Receptors," Bevan et al. "Cellular Mechanisms of the Action of Capsaicin," and James et al. "The Capsaicin Receptor," all in Capsaicin in the Study of Pain, 1993 Academic Press Limited, pgs. 1-26, 27-44, and 83-104, respectively; Bevan et al. 1990, *supra*).

The analgesic properties of capsaicin and capsaicinoids are of much interest for their uses in 15 the treatment of pain and inflammation associated with a variety of disorders (see, e.g., Fusco et al. 1997 Drugs 53:909-914; Towheed et al. 1997 Semin. Arthritis Rheum 26:755-770; Appendino et al. 1997 Life Sci 60:681-696 (describing activities and application of resiniferatoxin); Campbell et al. "Clinical 20 Applications of Capsaicin and Its Analogues" in Capsaicin in the Study of Pain 1993, Academic Press pgs. 255-272). Although capsaicin and capsaicin related compounds can evoke the sensation of pain, cause hyperalgesia, activate autonomic reflexes (e.g., elicit changes in blood pressure), and cause 25 release of peptides and other putative transmitters from nerve terminals (e.g., to induce bronchoconstriction and inflammation), prolonged exposure of sensory neurons to these compounds leads to desensitization of the neurons to multiple modalities of noxious sensory stimuli without compromising normal mechanical sensitivity or motor function, and without apparent central nervous system depression. It is this final phenomena that makes capsaicins and related compounds of great interest and potential therapeutic value.

Despite the intense interest in capsaicin and related compounds and their effects upon sensory afferent, the receptor(s) through which these compounds mediate their effects have eluded isolation and molecular characterization. Thus, the development of elegant systems for screening or characterizing 30 new capsaicin receptor-binding compounds, or for identifying endogenous, tissue-derived mediators of pain and/or inflammation, have been severely hampered. To date the only means of assessing the activity of compounds as capsaicin receptor agonists or antagonists has been to examined their effects on sensory neurons in culture or in intact animals. The present invention solves this problem.

SUMMARY

The present invention features vanilloid receptor polypeptides and vanilloid receptor-related polypeptides, specifically the capsaicin receptor and capsaicin receptor-related polypeptides, as well as nucleotide sequences 5 encoding capsaicin receptor and capsaicin receptor-related polypeptides. In related aspects the invention features expression vectors and host cells comprising polynucleotides that encode capsaicin receptor or capsaicin receptor-related polypeptide. In other related aspects, the invention features transgenic animals having altered capsaicin receptor expression, due to, for 10 example, the presence of an exogenous wild-type or modified capsaicin receptor-encoding polynucleotide sequence. The present invention also relates to antibodies that bind specifically to a capsaicin receptor polypeptide and/or capsaicin receptor-related polypeptide, and methods for producing capsaicin receptor and capsaicin receptor-related polypeptides.

15 In one aspect the invention features a method for identifying compounds that bind a capsaicin receptor polypeptide, preferably a compound that binds a capsaicin receptor polypeptide and affects a cellular response associated with capsaicin receptor biological activity (e.g., intracellular calcium flux).

20 In another aspect the invention features a method for detecting a vanilloid compound in a sample, where the vanilloid compound has activity in binding a capsaicin receptor polypeptide, by contacting a sample suspected of containing a vanilloid compound with a cell (e.g., an oocyte (e.g., an amphibian oocyte) or a mammalian cell) expressing a capsaicin receptor 25 polypeptide and detecting an alteration of a cellular response associated with capsaicin receptor activity in the capsaicin receptor-expressing host cell. Preferably, the cellular response associated with capsaicin receptor activity is an alteration of intracellular calcium levels in the capsaicin receptor-expressing host cell. The method can be used to detect vanilloid compounds 30 in samples derived from natural products (e.g., natural product extracts) or can be used to screen candidate compounds for use as analgesics (e.g., vanilloid analogs, therapeutic antibodies, antisense oligonucleotides, capsaicin receptor-encoding nucleotides for replacement gene therapy), flavor-enhancing agents, etc.

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Yet another aspect of the invention relates to use of capsaicin receptor polypeptides and specific antibodies thereto for the diagnosis and treatment of human disease and painful syndromes.

In another aspect the invention features transgenic, non-human

- 5 mammals expressing a capsaicin receptor-encoding transgene, and use of such transgenic mammals for use in screening of candidate capsaicin receptor agonist and antagonist compounds.

It is desirable to provide isolated polynucleotides for use in expression of capsaicin receptor and capsaicin receptor-related polypeptides (e.g., in a

- 10 recombinant host cell or in a target cell as part of organochemotherapy) and for use in, for example, identification of capsaicin receptor-binding compounds (especially those compounds that affect capsaicin receptor-mediated activity).

Throughout this specification the word "comprise", or variations such

- 15 as "comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

Any discussion of documents, acts, materials, devices, articles or the

- 20 like which has been included in the present specification is solely for the purpose of providing a context for the present invention. It is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present invention as it existed, particularly in Australia, before the priority date of
- 25 each claim of this application.

The invention will not be described in further detail.



BRIEF DESCRIPTION OF THE FIGURES

Fig. 1A shows the putative domains present in the capsaicin receptor amino acid sequence. Open boxes delineate ankyrin repeat domains; black boxes indicate predicted transmembrane domains; and the grey box indicates a possible pore-loop region. Bullets denote predicted protein 5 kinase A phosphorylation sites.

Fig. 1B shows the predicted membrane topology and domain structure of the capsaicin receptor. Open circles labeled "A" denote ankyrin domains; black areas denote transmembrane domains; and the grey shaded area indicates a possible pore-loop region. "i" and "o" denote the inner and outer membrane leaflets, respectively.

Fig. 1C shows the alignment of the capsaicin receptor VR1 with related sequences. Identical residues are darkly shaded and conservative substitutions are lightly shaded.

Fig. 2 is a current trace of whole cell voltage clamp analysis of capsaicin receptor-expressing HEK293 cells.

Fig. 3 is a plot of the voltage steps (400ms) from -100 mV to +40mV for the data presented in 15 Figure 3.

Fig. 4 is a graph illustrating the current-voltage relationship of the data from Figure 4.

Fig. 5 is a graph of the voltage generated across membranes of recombinant capsaicin receptor-expressing cells when exposed to capsaicin and tested under conditions of varying ionic compositions. a = NaCl; b= KCl; c = CsCl; d = MgCl₂; e = CaCl₂.

Fig. 6A through 19. 6F are graphs showing the effects of extracellular calcium upon capsaicin-induced current in whole-cell voltage clamp experiments.

Fig. 7 is graph illustrating the single channel behavior of capsaicin-induced current in capsaicin receptor-expressing HEK293 cells using outside-out (O/O) and inside-out (I/O) patches.

Fig. 8 is a graph showing the current-voltage relationship of the data obtained in Fig. 7.

Fig. 9A is a graph showing the effects of capsaicin and resiniferatoxin upon current in whole-cell voltage clamp experiments in *Xenopus* oocytes expressing the capsaicin receptor. Bars denote duration of agonist application. Membrane currents were recorded in the whole cell voltage clamp configuration ($V_{hold} = -40$ mV).

Fig. 9B is a graph showing the concentration-response curve for capsaicin (squares) and 30 resiniferatoxin (open circles) in VR1-expressing oocytes. In Fig. 9B, the membrane currents were normalized in each oocyte to a response obtained with 1 μ M capsaicin and expressed as a percent of maximal response to capsaicin. Each point represents mean values (\pm s.e.m.) from 5 independent oocytes.

Fig. 10A is a graph showing the effects of capsazepine upon capsaicin-induced current in 35 whole cell voltage clamp experiments. Slash marks represent wash out periods of 2 and 3 min, respectively (n = 3). cap = capsaicin; cpz = capsazepine; RR = ruthenium red. Each point represents 4 independent oocytes. Current response were normalized to that elicited by capsaicin in each oocyte

(0.6 μ M, open diamond). Slash marks denote 2 and 12 minute wash out periods, respectively (n=3).

Fig. 10B is a graph showing the capsazepine inhibition curve of capsaicin response in whole cell voltage clamp studies.

5 Fig. 11 is a histogram with corresponding current traces reflecting the relative capsaicin content of several different hot peppers.

Fig. 12 is a graph showing induction of cell death in HEK293 cells transiently transfected with capsaicin receptor-encoding cDNA. Open bars = cells exposed to carrier alone (ethanol); filled bars = cells exposed to capsaicin; pcDNA3 = control cells without capsaicin receptor-encoding DNA; VR1 10 (1:50) = cells transiently transfected with capsaicin receptor-encoding cDNA diluted 1:50 with control pcDNA3; and VR1 = cells transiently transfected with capsaicin receptor-encoding cDNA alone. Asterisks indicate a significant difference from ethanol-treated cells.

15 Fig. 13 is a current trace showing the effect of hydrogen ions upon capsaicin receptor activity in oocytes expressing capsaicin receptor. cap on = time of capsaicin introduction; cap off = time of 20 capsaicin wash out. The pH of the bath solution was changed during the experiment as indicated by the horizontal bars.

Fig. 14 is a graph showing a summary of the current response obtained from nine independent 25 capsaicin receptor-expressing oocytes. The grey portion of each bar indicates peak current evoked by capsaicin at pH 7.6, while the black portion represents the additional current evoked by changing the bath solution to pH 6.3.

Fig. 15A is a current trace showing the effects of heat and capsaicin upon capsaicin receptor activity in capsaicin receptor-expressing HEK293 cells as determined by whole patch clamp analysis.

Fig. 15B is a graph showing the current-voltage relationship of the data obtained in Fig. 15A.

Fig. 16 is a graph showing activation of capsaicin receptor in capsaicin receptor-expressing 25 *Xenopus* oocytes by noxious, but not innocuous, heat. The asterisk indicates a significant difference from control water-injected oocytes.

Fig. 17 provides representative current traces of the effects of capsaicin, heat, and heat plus ruthenium red (RR) upon capsaicin receptor-expressing *Xenopus* oocytes and control water-injected oocytes.

30 Fig. 18 is a schematic illustrating the relationship between rat VR1, rat VRRP-1, and the human EST sequence AA321554.

DETAILED DESCRIPTION OF THE INVENTION

Definitions

"Polynucleotide" as used herein refers to an oligonucleotide, nucleotide, and fragments or portions thereof, as well as to peptide nucleic acids (PNA), fragments, portions or antisense molecules thereof, and to DNA or RNA of genomic or synthetic origin which can be single- or double-stranded, and represent the sense or antisense strand. Where "polynucleotide" is used to refer to a specific polynucleotide sequence (e.g. a capsaicin receptor-encoding polynucleotide or a capsaicin receptor-related polypeptide-encoding polynucleotide), "polynucleotide" is meant to encompass polynucleotides that encode a polypeptide that is functionally equivalent to the recited polypeptide, e.g., polynucleotides that are degenerate variants, or polynucleotides that encode biologically active variants or fragments of the recited polypeptide. Similarly, "polypeptide" as used herein refers to an oligopeptide, peptide, or protein. Where "polypeptide" is recited herein to refer to an amino acid sequence of a naturally-occurring protein molecule, "polypeptide" and like terms are not meant to limit the amino acid sequence to the complete, native amino acid sequence associated with the recited protein molecule. By 15 "antisense polynucleotide" is meant a polynucleotide having a nucleotide sequence complementary to a given polynucleotide sequence (e.g., a polynucleotide sequence encoding a capsaicin receptor) including polynucleotide sequences associated with the transcription or translation of the given polynucleotide sequence (e.g., a promoter of a polynucleotide encoding capsaicin receptor), where the antisense polynucleotide is capable of hybridizing to a capsaicin receptor polynucleotide sequence. 20 Of particular interest are antisense polynucleotides capable of inhibiting transcription and/or translation of a capsaicin receptor-encoding or capsaicin receptor-related polypeptide-encoding polynucleotide either in vitro or in vivo.

"Peptide nucleic acid" as used herein refers to a molecule which comprises an oligomer to which an amino acid residue, such as lysine, and an amino group have been added. These small 25 molecules, also designated anti-gene agents, stop transcript elongation by binding to their complementary (template) strand of nucleic acid (Nielsen et al 1993 Anticancer Drug Des 8:53-63).

As used herein, "capsaicin receptor" or "capsaicin receptor polypeptide" means a recombinant or nonrecombinant polypeptide having an amino acid sequence of i) a native capsaicin receptor polypeptide, ii) a biologically active fragment of a capsaicin receptor polypeptide, iii) biologically active 30 polypeptide analogs of a capsaicin receptor polypeptide, or iv) a biologically active variant of a capsaicin receptor polypeptide. Capsaicin receptor polypeptides of the invention can be obtained from any species, particularly mammalian, including human, rodentia (e.g., murine or rat), bovine, ovine, porcine, murine, or equine, preferably rat or human, from any source whether natural, synthetic, semi-synthetic or recombinant. The term "capsaicin receptor" as used herein encompasses the vanilloid receptor 35 subtype 1(VR1) described in detail herein, but is not meant to be limited to VR1, and particularly may be generically used to refer to the receptor subtypes VR1 and VR2.

As used herein, "capsaicin receptor-related polypeptide" means a recombinant or nonrecombinant polypeptide having an amino acid sequence of i) a native capsaicin receptor-related

polypeptide, ii) a biologically active fragment of a capsaicin receptor-related polypeptide, iii) biologically active polypeptide analogs of a capsaicin receptor-related polypeptide, or iv) a biologically active variant of a capsaicin receptor-related polypeptide, herein referred to as "VRRP-1", or "VR2". Capsaicin receptor polypeptides of the invention can be obtained from any species, particularly a mammalian species, including human, rodentia (e.g., murine or rat), bovine, ovine, porcine, murine, or equine, preferably rat or human, from any source whether natural, synthetic, semi-synthetic or recombinant. The term "capsaicin receptor-related polypeptide" as used herein also encompasses any polypeptide having at least about 40% identity, preferably at least about 45% identity, more preferably at least about 49% identity to an amino acid sequence of a capsaicin receptor polypeptide of the same species (e.g., rat or human capsaicin receptor polypeptide). The term "capsaicin receptor-related polypeptide-encoding sequence" also encompasses a nucleotide sequence having at least about 50% identity, preferably at least about 55% identity, more preferably at least about 59% identity to a nucleotide sequence of a capsaicin receptor polypeptide of the same species. In one embodiment, the capsaicin receptor-related polypeptide interacts with capsaicin receptor. "Capsaicin receptor-related polypeptide" as used herein encompasses the vanilloid receptor-related polypeptide 1 (VRRP-1) described in detail herein, but is not meant to be limited to VRRP-1.

As used herein, "antigenic amino acid sequence" means an amino acid sequence that, either alone or in association with a carrier molecule, can elicit an antibody response in a mammal.

A "variant" of a capsaicin receptor or capsaicin receptor-related polypeptide is defined as an amino acid sequence that is altered by one or more amino acids. The variant can have "conservative" changes, wherein a substituted amino acid has similar structural or chemical properties, e.g., replacement of leucine with isoleucine. More rarely, a variant can have "nonconservative" changes, e.g., replacement of a glycine with a tryptophan. Similar minor variations can also include amino acid deletions or insertions, or both. Guidance in determining which and how many amino acid residues may be substituted, inserted or deleted without abolishing biological or immunological activity can be found using computer programs well known in the art, for example, DNASTar software.

A "deletion" is defined as a change in either amino acid or nucleotide sequence in which one or more amino acid or nucleotide residues, respectively, are absent as compared to an amino acid sequence or nucleotide sequence of a naturally occurring capsaicin receptor or capsaicin receptor-related polypeptide.

An "insertion" or "addition" is that change in an amino acid or nucleotide sequence which has resulted in the addition of one or more amino acid or nucleotide residues, respectively, as compared to an amino acid sequence or nucleotide sequence of a naturally occurring capsaicin receptor or capsaicin receptor-related polypeptide.

A "substitution" results from the replacement of one or more amino acids or nucleotides by different amino acids or nucleotides, respectively as compared to an amino acid sequence or nucleotide sequence of a naturally occurring capsaicin receptor or capsaicin receptor-related polypeptide.

The term "biologically active" refers to capsaicin receptor polypeptide or capsaicin receptor-related polypeptide having structural, regulatory, or biochemical functions of a naturally occurring capsaicin receptor polypeptide or capsaicin receptor-related polypeptide, respectively. Likewise, "immunologically active" defines the capability of the natural, recombinant or synthetic capsaicin receptor (or capsaicin receptor-related polypeptide), or any oligopeptide thereof, to induce a specific immune response in appropriate animals or cells and to bind with specific antibodies.

The term "derivative" as used herein refers to the chemical modification of a nucleic acid encoding a capsaicin receptor or a capsaicin receptor-related polypeptide. Illustrative of such modifications would be replacement of hydrogen by an alkyl, acyl, or amino group. A nucleic acid derivative would encode a polypeptide which retains essential biological characteristics of a natural capsaicin receptor or capsaicin receptor-related polypeptide.

As used herein the term "isolated" is meant to describe a compound of interest (e.g., either a polynucleotide or a polypeptide) that is in an environment different from that in which the compound naturally occurs. "Isolated" is meant to include compounds that are within samples that are substantially enriched for the compound of interest and/or in which the compound of interest is partially or substantially purified.

As used herein, the term "substantially purified" refers to a compound (e.g., either a polynucleotide or a polypeptide) that is removed from its natural environment and is at least 60% free, preferably 75% free, and most preferably 90% free from other components with which it is naturally associated.

"Stringency" typically occurs in a range from about $T_m - 5^\circ\text{C}$ (5°C below the T_m of the probe) to about 20°C to 25°C below T_m . As will be understood by those of skill in the art, a stringency hybridization can be used to identify or detect identical polynucleotide sequences or to identify or detect similar or related polynucleotide sequences.

The term "hybridization" as used herein shall include "any process by which a strand of nucleic acid joins with a complementary strand through base pairing" (Coombs 1994 Dictionary of Biotechnology, Stockton Press, New York NY). Amplification as carried out in the polymerase chain reaction technologies is described in Dieffenbach et al. 1995, PCR Primer, a Laboratory Manual, Cold Spring Harbor Press, Plainview NY.

The term "transgene" is used herein to describe genetic material which has been or is about to be artificially inserted into the genome of a mammalian, particularly a mammalian cell of a living animal.

By "transgenic animal" is meant a non-human animal, usually a mammal, having a non-endogenous (i.e., heterologous) nucleic acid sequence present as an extrachromosomal element in a portion of its cells or stably integrated into its germ line DNA (i.e., in the genomic sequence of most or all of its cells). Heterologous nucleic acid is introduced into the germ line of such transgenic animals by genetic manipulation of, for example, embryos or embryonic stem cells of the host animal.

A "knock-out" of a target gene means an alteration in the sequence of the gene that results in a decrease of function of the target gene, preferably such that target gene expression is undetectable or insignificant. For example, a knock-out of a capsaicin receptor gene means that function of the capsaicin receptor has been substantially decreased so that capsaicin receptor expression is not 5 detectable or only present at insignificant levels. "Knock-out" transgenics of the invention can be transgenic animals having a heterozygous or homozygous knock-out of the capsaicin receptor gene or capsaicin receptor-related polypeptide encoding sequence. "Knock-outs" also include conditional knock-outs, where alteration of the target gene can occur upon, for example, exposure of the animal to a substance that promotes target gene alteration, introduction of an enzyme that promotes 10 recombination at the target gene site (e.g., Cre in the Cre-lox system), or other method for directing the target gene alteration postnatally.

A "knock-in" of a target gene means an alteration in a host cell genome that results in altered expression (e.g., increased (including ectopic) or decreased expression) of the target gene, e.g., by introduction of an additional copy of the target gene, or by operatively inserting a regulatory sequence 15 that provides for enhanced expression of an endogenous copy of the target gene. For example, "knock-in" transgenics of the invention can be transgenic animals having a heterozygous or homozygous knock-in of the capsaicin receptor gene. "Knock-ins" also encompass conditional knock-ins.

The major genetic sequences provided herein are as follows:

SEQ ID NO	Sequence
1	Rat VR1 cDNA sequence
2	Rat VR1 amino acid sequence
3	Rat VRRP-1 (VR2) cDNA sequence
4	Rat VRRP-1 (VR2) amino acid sequence
5	Human VRRP-1 consensus sequence, region A
6	Human VRRP-1 consensus sequence, region B
7	Human VRRP-1 consensus sequence, region C
8	EST AA321554 DNA sequence
9	EST AA321554 amino acid sequence
10	mouse VR1 cDNA sequence
11	mouse VR1 amino acid sequence
12	primer
13	primer
14	Rat VR1 amino acid sequence
15	Human T11251 amino acid sequence
16	Caliphora z80230 amino acid sequence
17	Drosophila TRP amino acid sequence
18	Bocine x99792 amino acid sequence

19	<i>E. elegans</i> z72508 amino acid sequence
20	Human VRRP-1 (VR2) DNA sequence
21	Human VRRP-1 (VR2) DNA sequence
22	Human VRRP-1 (VR2) DNA sequence
23	Human VRRP-1 (VR2) amino acid sequence
24	Chicken VR1 cDNA sequence
25	Chicken VR1 amino acid sequence
26	Human VR1 cDNA sequence
27	Human VR1 amino acid sequence

Overview of the Invention

The present invention is based upon the identification and isolation of a polynucleotide sequence encoding a capsaicin receptor polypeptide (e.g., the vanilloid receptor subtype 1 (VR1) polypeptide described herein) and a capsaicin receptor-related polypeptide (e.g., the vanilloid receptor-related polypeptide 1 (VRRP-1; or VR2) described herein). The corresponding genetic sequences are provided in the Seqlist, and are listed in the table provided above. Accordingly, the present invention encompasses such polynucleotides encoding capsaicin receptor and/or capsaicin receptor-related polypeptides, as well as the capsaicin receptor and capsaicin receptor-related polypeptides encoded by such polynucleotides.

A capsaicin receptor polypeptide-encoding polynucleotide was first isolated by virtue of the capsaicin receptor polypeptide-encoding sequence to facilitate expression of a functional capsaicin receptor in a cellular assay. In short, the capsaicin receptor polypeptide-encoding polynucleotide, when expressed in a mammalian or amphibian host cell, facilitated an increase in intracellular calcium concentration in the host cell upon exposure to the agonist capsaicin. This work lead to identification and isolation of a polynucleotide sequence encoding a capsaicin receptor referred to herein as a vanilloid receptor subtype 1 (VR1). The capsaicin receptor-encoding VR1 sequence was then used to isolate by PCR amplification a sequences encoding related polypeptides, resulting in isolation and identification of sequences encoding a capsaicin receptor-related polypeptide, of which VRRP-1 (VR2) is exemplary.

The invention also encompasses use of capsaicin receptor and capsaicin receptor-related polypeptide nucleic acid and amino acid sequences in the identification of capsaicin receptor-binding compounds, particularly capsaicin receptor-binding compounds having capsaicin receptor agonist or antagonist activity. The invention further encompasses the use of the polynucleotides disclosed herein to facilitate identification and isolation of polynucleotide and polypeptide sequences having homology to a capsaicin receptor and/or capsaicin receptor-related polypeptide of the invention; as well as the diagnosis, prevention and treatment of disease and/or pain syndromes associated with capsaicin receptor biological activity.

The polynucleotides of the invention can also be used as a molecular probe with which to determine the structure, location, and expression of capsaicin receptor, receptor subtypes, and capsaicin receptor-related polypeptides in mammals (including humans) and to investigate potential associations between disease states or clinical disorders (particularly those involving acute and chronic pain or inflammation) and defects or alterations in receptor structure, expression, or function.

Capsaicin Receptor and Capsaicin Receptor-Related Polypeptide Coding Sequences

In accordance with the invention, any nucleic acid sequence that encodes an amino acid sequence of a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide can be used to generate recombinant molecules which express a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide, respectively. The nucleic acid compositions used in the subject invention may encode all or a part of a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide of the invention as appropriate. Fragments may be obtained of the DNA sequence by chemically synthesizing oligonucleotides in accordance with conventional methods, by restriction enzyme digestion, by PCR amplification, etc. For the most part, DNA fragments will be of at least about ten contiguous nucleotides, usually at least about 15 nt, more usually at least about 18 nt to about 20 nt, more usually at least about 25 nt to about 50 nt. Such small DNA fragments are useful as primers for PCR, hybridization screening, etc. Larger DNA fragments, i.e. greater than 100 nt are useful for production of the encoded polypeptide.

The nucleic acid and deduced amino acid sequences of rat capsaicin receptor (subtype VR1) are provided as SEQ ID NOS:1 and 2. Nucleic acid and deduced amino acid sequences of a human capsaicin receptor (subtype VR1) are provided as SEQ ID NOS:8-9; and 26-27). A nucleotide sequence encoding murine capsaicin receptor subtype VR1 comprises the sequences of SEQ ID NOS:10 and 11. The chicken capsaicin receptor subtype VR1 is provided as SEQ ID NO:24 and 25.

The nucleic acid and deduced amino acid sequence of rat capsaicin receptor-related polypeptide 1 (VRRP-1; or subtype VR2) are provided as SEQ ID NO:3 and 4, respectively. A sequence encoding a human capsaicin receptor-related polypeptide (referred to as human VR2) comprises the nucleotide sequence SEQ ID NOS:5-7; and 20-23.

The present invention also encompasses variants of capsaicin receptor and capsaicin receptor-related polypeptides. A preferred variant is one having at least 80% amino acid sequence similarity, more preferably at least 90% amino acid sequence similarity, still more preferably at least 95% amino acid sequence similarity to an amino acid sequence of a capsaicin receptor, subtype VR1 or VR2.

It will be appreciated by those skilled in the art that as a result of the degeneracy of the genetic code, a multitude of degenerate variants of nucleotide sequences encoding capsaicin receptor and capsaicin receptor-related polypeptides, some bearing minimal homology to the nucleotide sequences of any known and naturally occurring gene, can be produced. The invention contemplates each and every possible variation of nucleotide sequence that can be made by selecting combinations based on possible codon choices. These combinations are made in accordance with the standard triplet genetic

code as applied to the nucleotide sequence of naturally occurring capsaicin receptor or capsaicin receptor-related polypeptide, and all such variations are to be considered as being specifically disclosed herein.

Although nucleotide sequences that encode capsaicin receptor polypeptides, and their variants 5 are preferably capable of hybridizing to the nucleotide sequence of the naturally occurring polypeptides under appropriately selected conditions of stringency, it may be advantageous to produce nucleotide sequences encoding receptors or their derivatives possessing a substantially different codon usage. Codons can be selected to increase the rate at which expression of the polypeptide occurs in a particular prokaryotic or eukaryotic expression host in accordance with the frequency with which 10 particular codons are utilized by the host. Other reasons for substantially altering the nucleotide sequence encoding capsaicin receptor, capsaicin receptor-related polypeptide, and their derivatives without altering the encoded amino acid sequences include the production of RNA transcripts having more desirable properties (e.g., increased half-life) than transcripts produced from the naturally occurring sequence.

15 Nucleotide sequences encoding a capsaicin receptor polypeptide, capsaicin receptor-related polypeptide, and/or their derivatives can be synthesized entirely by synthetic chemistry, after which the synthetic gene can be inserted into any of the many available DNA vectors and expression systems using reagents that are well known in the art at the time of the filing of this application. Moreover, synthetic chemistry can be used to introduce mutations into a sequence encoding a capsaicin receptor 20 polypeptide or capsaicin receptor-related polypeptide.

Also included within the scope of the present invention are polynucleotide sequences that are capable of hybridizing to the nucleotide sequence of any of the provided nucleic acid sequences of capsaicin receptors, subtypes VR1 or VR2. Of particular interest are polynucleotide sequence capable 25 of hybridizing under various conditions of stringency to the coding sequence for capsaicin receptor or capsaicin receptor-related polypeptide (e.g., nucleotides 81-2594 of SEQ ID NO:1), to a region of a capsaicin receptor-encoding sequence or capsaicin receptor-related polypeptide-encoding sequence that shares homology with other such sequences (e.g., a sequence encoding a contiguous stretch of amino acid residues present in SEQ ID NO:2 (e.g., amino acid residues 636 to 706 of SEQ ID NO:2), and other sequences representing areas of homology with other capsaicin receptor-encoding 30 sequences and/or capsaicin receptor-related polypeptides-encoding sequences, as well as sequences that uniquely identify capsaicin receptor-encoding sequences or capsaicin receptor-related polypeptide-encoding sequences of various species. Of particular interest are capsaicin receptor VR1 or VR2 polynucleotide sequences encoding a human capsaicin receptor polypeptide or human capsaicin receptor-related polypeptide. Hybridization conditions are based on the melting temperature (T_m) of 35 the nucleic acid binding complex or probe, as taught in Berger et al. 1987 Guide to Molecular Cloning Techniques, Methods in Enzymology, Vol 152, Academic Press, San Diego CA incorporated herein by reference, and can be used at a defined stringency.

Altered nucleic acid sequences encoding capsaicin receptor or capsaicin receptor-related polypeptide that can be used in accordance with the invention include deletions, insertions or substitutions of different nucleotides resulting in a polynucleotide that encodes the same or a functionally equivalent capsaicin receptor or capsaicin receptor-related polypeptide. The protein can also comprise 5 deletions, insertions or substitutions of amino acid residues that result in a polypeptide that is functionally equivalent to capsaicin receptor or capsaicin receptor-related polypeptide. Deliberate amino acid substitutions can be made on the basis of similarity in polarity, charge, solubility, hydrophobicity, hydrophilicity, and/or the amphipathic nature of the residues with the proviso that biological activity of capsaicin receptor is retained. For example, negatively charged amino acids include aspartic acid and 10 glutamic acid; positively charged amino acids include lysine and arginine; and amino acids with uncharged polar head groups having similar hydrophilicity values include leucine, isoleucine, valine; glycine, alanine; asparagine, glutamine; serine, threonine phenylalanine, and tyrosine.

Alleles of capsaicin receptor, as well as alleles of capsaicin receptor-related polypeptide, are also encompassed by the present invention. As used herein, an "allele" or "allelic sequence" is an 15 alternative form of a capsaicin receptor or capsaicin receptor-related polypeptide. Alleles result from a mutation (*i.e.*, an alteration in the nucleic acid sequence) and generally produce altered mRNAs and/or polypeptides that may or may not have an altered structure or function relative to naturally-occurring capsaicin receptor or capsaicin receptor-related polypeptide. Any given gene may have none, one, or many allelic forms. Common mutational changes that give rise to alleles are generally ascribed 20 to natural deletions, additions or substitutions of amino acids. Each of these types of changes may occur alone or in combination with the other changes, and may occur once or multiple times in a given sequence.

Isolating Capsaicin Receptor-Encoding and Capsaicin Receptor-Related Polypeptide-Encoding Polynucleotides from Other Species

25 Capsaicin receptor polypeptide-encoding polynucleotides, capsaicin receptor-related polypeptide-encoding polynucleotides, or portions thereof can be used as probes for identifying and cloning homologs of the capsaicin receptor and capsaicin receptor-related polypeptide sequences disclosed herein. Of particular interest are mammalian homologs (especially the human homology of the disclosed rat capsaicin receptor-encoding and capsaicin receptor-related polypeptide-encoding 30 sequences), where the homologs have substantial sequence similarity to one another, *i.e.* at least 40%, usually at least 60%, more usually at least 75%, usually at least 90%, more usually at least 95% sequence similarity. Mammalian homologs of capsaicin receptor may also share a high degree of similarity to the capsaicin receptor disclosed herein in the vicinity of the predicted pore-loop and sixth transmembrane domains. At these regions the capsaicin receptor homologs may exhibit high sequence 35 similarity, *e.g.*, at least about 40% amino acid sequence identity, usually at least about 60% to 75% amino acid sequence identity, with at least about 40% nucleotide sequence similarity, usually at least about 60% to 90% nucleotide sequence similarity.

Sequence similarity is calculated based on a reference sequence, which may be a subset of a larger sequence, such as a conserved motif, coding region, flanking region, etc. A reference sequence will usually be at least about 18 nt long, more usually at least about 30 nt long, and may extend to the complete sequence that is being compared. Algorithms for sequence analysis are known 5 in the art, such as BLAST, described in Altschul *et al.* (1990) *J Mol Biol* 215:403-10. The specificity of the probe, whether it is made from a highly specific region, e.g., 10 unique nucleotides in the 5' regulatory region, or a less specific region, e.g., especially in the 3' region, and the stringency of the hybridization or amplification (maximal, high, intermediate or low) will determine whether the probe identifies only naturally occurring sequences encoding capsaicin receptor, alleles or related sequences.

10 Where the probes of the invention are used in the detection of related sequences, the probes preferably comprise at least 30%, more preferably at least 50% of the nucleotides from any of the capsaicin receptor polypeptide-encoding sequences or the capsaicin receptor-related polypeptide-encoding described herein. The hybridization probes of the subject invention can be derived from the provided VR1 and VR2 nucleotide sequences, or from their corresponding genomic sequences 15 including promoters, enhancer elements and introns of the naturally occurring capsaicin receptor-encoding sequence. Hybridization probes can be detectably labeled with a variety of reporter molecules, including radionuclides (e.g., ^{32}P or ^{35}S), or enzymatic labels (e.g., alkaline phosphatase coupled to the probe via avidin/biotin coupling systems), and the like.

20 Specific hybridization probes can also be produced by cloning the provided nucleic acid sequences into vectors for production of mRNA probes. Such vectors, which are known in the art and are commercially available, can be used to synthesize RNA probes in vitro using an appropriate RNA polymerase (e.g., T7 or SP6 RNA polymerase) and appropriate radioactively labeled nucleotides.

25 Nucleic acids having sequence similarity are detected by hybridization under low stringency conditions, for example, at 50°C and 10XSSC (0.9 M saline/0.09 M sodium citrate) and remain bound when subjected to washing at 55°C in 1XSSC. Sequence identity may be determined by hybridization 30 under stringent conditions, for example, at 50°C or higher and 0.1XSSC (9 mM saline/0.9 mM sodium citrate). By using probes, particularly labeled probes of DNA sequences, one can isolate homologous or related genes. The source of homologous genes may be any species, e.g. primate species, particularly human; rodents, such as rats and mice, canines, felines, bovines, ovines, equines, yeast, 35 *Drosophila*, *Caenorhabditis*, etc. Of particular interest is the identification and isolation of human capsaicin receptor polypeptide-encoding polynucleotides and human capsaicin receptor-related polypeptide-encoding polynucleotides.

The capsaicin receptor and capsaicin receptor-related polypeptide nucleic acid sequences can also be used to generate hybridization probes for mapping a naturally occurring genomic sequence. 35 The sequence can be mapped to a particular chromosome or to a specific region of the chromosome using well known techniques. These include in situ hybridization to chromosomal spreads, flow-sorted chromosomal preparations, or artificial chromosome constructions such as yeast artificial chromosomes, bacterial artificial chromosomes, bacterial P1 constructions or single chromosome cDNA

libraries as reviewed in Price 1993; Blood Rev 7:127-34 and Trask 1991; Trends Genet 7:149-54. Fluorescent in situ hybridization of chromosome spreads is described in, for example, Verma et al 1988 Human Chromosomes: A Manual of Basic Techniques, Pergamon Press, New York NY.

Information from chromosomal mapping of sequences encoding capsaicin receptor or capsaicin receptor-related polypeptide can be correlated with additional genetic map data. Correlation between the location of a capsaicin receptor-encoding sequence, or a capsaicin receptor-related polypeptide-encoding sequence, on a physical chromosomal map and a specific disease (or predisposition to a specific disease) can help delimit the region of DNA associated with that genetic disease. The nucleotide sequences of the subject invention can be used to detect differences in gene sequences (e.g., differences in the chromosomal location due to translocation, inversion, etc. or other differences in the capsaicin receptor-encoding region due to insertional mutation(s) or deletion of capsaicin receptor- or capsaicin receptor-related polypeptide-encoding sequences) between normal, carrier, or affected individuals. Exemplary disorders that may benefit from such information include, but are not necessarily limited to, complex regional pain syndromes, reflex sympathetic dystrophies, postherpetic neuralgia, psoriasis, reactive airway diseases (e.g., asthma, chronic obstructive pulmonary disease), osteoarthritis, rheumatoid arthritis, diabetic neuropathy, AIDS-associated neuropathies, and hereditary neuropathies (e.g., associated with capsaicin receptor dysfunction).

Extending the Capsaicin Receptor-Encoding Polynucleotide Sequence

The polynucleotide sequence encoding capsaicin receptor or capsaicin receptor-related polypeptide can be extended utilizing partial nucleotide sequence and various methods known in the art to detect upstream sequences such as promoters and regulatory elements. Gobinda et al 1993; PCR Methods Applic 2:318-22 disclose "restriction-site" polymerase chain reaction (PCR) as a direct method which uses universal primers to retrieve unknown sequence adjacent to a known locus. First, genomic DNA is amplified in the presence of primer to a linker sequence and a primer specific to the known region. The amplified sequences are subjected to a second round of PCR with the same linker primer and another specific primer internal to the first one. Products of each round of PCR are transcribed with an appropriate RNA polymerase and sequenced using reverse transcriptase.

Inverse PCR can be used to amplify or extend sequences using divergent primers based on a known region (Triglia et al 1988 Nucleic Acids Res 16:8186). The primers can be designed using OLIGO® 4.06 Primer Analysis Software (1992; National Biosciences Inc, Plymouth MN), or another appropriate program, to be 22-30 nucleotides in length, to have a GC content of 50% or more, and to anneal to the target sequence at temperatures about 68°-72° C. This method uses several restriction enzymes to generate a suitable fragment in the known region of a gene. The fragment is then circularized by intramolecular ligation and used as a PCR template.

Capture PCR (Lagerstrom et al 1991 PCR Methods Applic 1:111-19) is a method for PCR amplification of DNA fragments adjacent to a known sequence in human and yeast artificial chromosome DNA. Capture PCR also requires multiple restriction enzyme digestions and ligations to

place an engineered double-stranded sequence into an unknown portion of the DNA molecule before PCR.

Another method that can be used to retrieve unknown sequences is that of Parker et al 1991; Nucleic Acids Res 19:3055-60. Additionally, one can use PCR, nested primers, and PromoterFinder 5 libraries to "walk in" genomic DNA (PromoterFinder™ Clontech (Palo Alto CA). This process avoids the need to screen libraries and is useful in finding intron/exon junctions. Preferably, the libraries used to identify full length cDNAs have been size-selected to include larger cDNAs. More preferably, the cDNA libraries used to identify full-length cDNAs are those generated using random primers, in that such libraries will contain more sequences comprising regions 5' of the sequence(s) of interest. A randomly 10 primed library can be particularly useful where oligo d(T) libraries do not yield a full-length cDNA. Genomic libraries are preferred for identification and isolation of 5' nontranslated regulatory regions of a sequence(s) of interest.

Capillary electrophoresis can be used to analyze the size of, or confirm the nucleotide sequence of, sequencing or PCR products. Systems for rapid sequencing are available from Perkin 15 Elmer, Beckman Instruments (Fullerton CA), and other companies. Capillary sequencing can employ flowable polymers for electrophoretic separation, four different, laser-activatable fluorescent dyes (one for each nucleotide), and a charge coupled device camera for detection of the wavelengths emitted by the fluorescent dyes. Output/light intensity is converted to electrical signal using appropriate software (e.g. Genotyper™ and Sequence Navigator™ from Perkin Elmer). The entire process from loading of 20 the samples to computer analysis and electronic data display is computer controlled. Capillary electrophoresis is particularly suited to the sequencing of small pieces of DNA that might be present in limited amounts in a particular sample. Capillary electrophoresis provides reproducible sequencing of up to 350 bp of M13 phage DNA in 30 min (Ruiz-Martinez et al 1993 Anal Chem 65:2851-2858).

25 Production of Polynucleotides Encoding Capsaicin Receptor or Capsaicin Receptor-Related Polypeptides

In accordance with the present invention, polynucleotide sequences that encode capsaicin receptor polypeptides or capsaicin receptor-related polypeptides (which capsaicin receptor polypeptides and capsaicin receptor-related polypeptides include fragments of the naturally-occurring polypeptide, 30 fusion proteins, and functional equivalents thereof) can be used in recombinant DNA molecules that direct the expression of capsaicin receptor or capsaicin receptor-related polypeptides in appropriate host cells. Due to the inherent degeneracy of the genetic code, other DNA sequences that encode substantially the same or a functionally equivalent amino acid sequence, can be used to clone and express capsaicin receptor or capsaicin receptor-related polypeptide. As will be understood by those 35 of skill in the art, it may be advantageous to produce capsaicin receptor-encoding nucleotide sequences and capsaicin receptor-related polypeptide-encoding nucleotide sequences possessing non-naturally occurring codons. Codons preferred by a particular prokaryotic or eukaryotic host (Murray et al 1989 Nuc Acids Res 17:477-508) can be selected, for example, to increase the rate of expression or to

produce recombinant RNA transcripts having a desirable characteristic(s) (e.g., longer half-life than transcripts produced from naturally occurring sequence).

The nucleotide sequences of the present invention can be engineered in order to alter an capsaicin receptor-encoding sequence or a capsaicin receptor-related polypeptide-encoding sequence 5 for a variety of reasons, including but not limited to, alterations that facilitate the cloning, processing and/or expression of the gene product. For example, mutations can be introduced using techniques that are well known in the art, e.g., site-directed mutagenesis to insert new restriction sites, alter glycosylation patterns, change codon preference, produce splice variants, etc.

In another embodiment of the invention, a natural, modified, or recombinant polynucleotide 10 encoding a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide can be ligated to a heterologous sequence to encode a fusion protein. Such fusion proteins can also be engineered to contain a cleavage site located between a capsaicin receptor polypeptide-encoding sequence (or capsaicin receptor-related polypeptide-encoding sequence) and a heterologous polypeptide sequence, such that the heterologous polypeptide sequence can be cleaved and purified away from the capsaicin 15 receptor polypeptide or capsaicin receptor-related polypeptide.

In an alternative embodiment of the invention, a nucleotide sequence encoding a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide can be synthesized, in whole or in part, using chemical methods well known in the art (see, e.g., Caruthers et al 1980 Nuc Acids Res Symp Ser 215-23, Horn et al (1980) Nuc Acids Res Symp Ser 225-32). Alternatively, the polypeptide itself can 20 be produced using chemical methods to synthesize an amino acid sequence of a capsaicin receptor or capsaicin receptor-related polypeptide, in whole or in part. For example, peptide synthesis can be performed using various solid-phase techniques (Roberge et al 1995 Science 269:202-204) and automated synthesis can be achieved, for example, using the ABI 431A Peptide Synthesizer (Perkin Elmer) in accordance with the instructions provided by the manufacturer.

25 The newly synthesized polypeptide can be substantially purified by preparative high performance liquid chromatography (e.g., Creighton 1983 Proteins, Structures and Molecular Principles, WH Freeman and Co, New York NY). The composition of the synthetic polypeptides can be confirmed by amino acid analysis or sequencing (e.g., the Edman degradation procedure; Creighton, *supra*). Additionally the amino acid sequence of capsaicin receptor, capsaicin receptor-related polypeptide, or 30 any part thereof, can be altered during direct synthesis and/or combined using chemical methods with sequences from other proteins, or any part thereof, to produce a variant polypeptide.

Capsaicin Receptor and Capsaicin Receptor-Related Polypeptide Expression Systems

The invention encompasses expression of capsaicin receptor polypeptides and capsaicin 35 receptor-related polypeptides individually or in combination (e.g., co-expression). In order to express a biologically active capsaicin receptor polypeptide and/or capsaicin receptor-related polypeptide, the nucleotide sequence encoding a capsaicin receptor polypeptide, a capsaicin receptor-related polypeptide, and/or a functional equivalent of either, is inserted into an appropriate expression vector,

i.e., a vector having the necessary elements for the transcription and translation of the inserted coding sequence. Methods well known to those skilled in the art can be used to construct expression vectors comprising a desired polypeptide-encoding sequence and appropriate transcriptional or translational controls. These methods include in vitro recombinant DNA techniques, synthetic techniques and in vivo 5 recombination or genetic recombination. Such techniques are described in Sambrook et al 1989 Molecular Cloning, A Laboratory Manual, Cold Spring Harbor Press, Plainview NY and Ausubel et al 1989 Current Protocols in Molecular Biology, John Wiley & Sons, New York NY.

A variety of expression vector/host cell systems can be utilized to express a capsaicin receptor polypeptide- and capsaicin receptor-related polypeptide-encoding sequence. These include, but are 10 not limited to, amphibian oocytes (e.g., *Xenopus* oocytes); microorganisms such as bacteria transformed with recombinant bacteriophage, plasmid or cosmid DNA expression vectors; yeast transformed with yeast expression vectors; insect cell systems infected with viral expression vectors (e.g., baculovirus); plant cell systems transfected with viral expression vectors (e.g., cauliflower mosaic virus, CaMV; tobacco mosaic virus, TMV) or transformed with bacterial expression vectors (e.g., Ti or 15 pBR322 plasmid); or animal (e.g., mammalian) cell systems. Preferably, the sequences of the present invention, particularly capsaicin receptor-encoding sequences, are expressed in a mammalian cell system (e.g., human embryonic kidney cells (e.g., HEK 293), an amphibian oocyte (e.g., by injecting *Xenopus* oocytes with complementary capsaicin receptor-encoding RNA), or other host cell that is easily propagated in culture and can be transformed or transfected to either transiently or stably express, 20 preferably stably express, a capsaicin receptor-encoding sequence and/or capsaicin receptor-related polypeptide-encoding sequence).

Host cells can be selected for capsaicin receptor polypeptide and/or capsaicin receptor-related polypeptide expression according to the ability of the cell to modulate the expression of the inserted sequences or to process the expressed protein in a desired fashion. Such modifications of the 25 polypeptide include, but are not limited to, acetylation, carboxylation, glycosylation, phosphorylation, lipidation and acylation. Post-translational processing that involves cleavage of a "pro" form of the protein may also be important for correct polypeptide folding, membrane insertion, and/or function. Host cells such as HEK 293, CHO, HeLa, MDCK, WI38, *Xenopus* oocytes, and others have specific 30 cellular machinery and characteristic mechanisms for such post-translational activities and may be chosen to ensure the correct modification and processing of the introduced, foreign polypeptide.

The vector(s) used for expression of a capsaicin receptor polypeptide and/or capsaicin receptor-related polypeptide will vary with a variety of factors including the host cell in which the capsaicin receptor polypeptide is to be expressed, whether capsaicin receptor polypeptide- and capsaicin receptor-related polypeptide sequences are to be co-expressed either from a single construct 35 or from separate constructs, and the intended use for the polypeptide produced. For example, when large quantities of a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide are required (e.g., for the antibody production), vectors that direct high-level expression of fusion proteins that can be readily purified may be desirable. Such vectors include, for example, bacterial expression

vectors, including multifunctional *E. coli* cloning and expression vectors such as Bluescript® (Stratagene; which provides for production of polypeptide-β-galactosidase hybrid proteins); and pGEX vectors (Promega, Madison WI; which provides for production of glutathione S-transferase (GST) fusion proteins. Where the host cell is yeast (e.g., *Saccharomyces cerevisiae*) a number of vectors containing 5 constitutive or inducible promoters such as alpha factor, alcohol oxidase and PGH can be used. For reviews, see Ausubel et al (supra) and Grant et al 1987 Methods in Enzymology 153:516-544.

Where the host cell is a mammalian cells, a number of expression systems can be used. For example, the expression vector can be derived from a viral-based expression system, such as an expression system derived from an adenovirus, SV40, CMV, or RSV nucleotide sequence. Expression 10 efficiency can be enhanced by including enhancers appropriate to the cell system in use (Scharf et al 1994 Results Probl Cell Differ 20:125-62; Bittner et al 1987 Methods in Enzymol 153:516-544) (e.g., the RSV enhancer can be used to increase expression in mammalian host cells).

The "control elements" or "regulatory sequences" of these systems, which vary in their strength and specificities, are those nontranslated regions of the vector, enhancers, promoters, and 3' 15 untranslated regions that interact with host cellular proteins to facilitate transcription and translation of a nucleotide sequence of interest. Depending on the vector system and host utilized, any number of suitable transcriptional and translational elements, including constitutive and inducible promoters, can be used. Such control elements or regulatory sequences are selected according to the host cell in which the capsaicin receptor-encoding polynucleotide and/or capsaicin receptor-related polypeptide- 20 encoding polynucleotide is to be expressed. For example, in mammalian cell systems, promoters from the mammalian genes or from mammalian viruses are most appropriate. Where it is desirable to generate a cell line containing multiple copies of a capsaicin receptor polypeptide-encoding sequence or a capsaicin receptor-related polypeptide-encoding sequence, vectors derived from SV40 or EBV can be used in conjunction with other optional vector elements, e.g., an appropriate selectable marker.

25 Specific initiation signals may also be required for efficient translation of a capsaicin receptor polypeptide- or capsaicin receptor-related polypeptide-encoding sequence, e.g., the ATG initiation codon and flanking sequences for bacterial expression. Where a native sequence, including its initiation codon and upstream sequences, is inserted into the appropriate expression vector, no additional translational control signals may be needed. However, where only coding sequence, or a portion 30 thereof, is inserted in an expression vector, exogenous transcriptional control signals including the ATG initiation codon must be provided. Furthermore, the initiation codon must be in the correct reading frame to ensure transcription of the entire insert. Exogenous transcriptional elements and initiation codons can be derived from various origins, and can be either natural or synthetic.

Where long-term, high-yield recombinant polypeptide production is desired, stable expression 35 is preferred. For example, cell lines that stably express capsaicin receptor and/or capsaicin receptor-related polypeptide can be transformed using expression vectors containing viral origins of replication or endogenous expression elements and a selectable marker gene. After introduction of the vector, cells can be grown in an enriched media before they are exposed to selective media. The selectable

marker, which confers resistance to the selective media, allows growth and recovery of cells that successfully express the introduced sequences. Resistant, stably transformed cells can be proliferated using tissue culture techniques appropriate to the host cell type.

Any number of selection systems can be used to recover transformed cell lines. These include, 5 but are not limited to, the herpes simplex virus thymidine kinase (Wigler et al 1977 Cell 11:223-32) and adenine phosphoribosyltransferase (Lowy et al 1980 Cell 22:817-23) genes which can be employed in tk- or aprt- cells, respectively. Also, antimetabolite or antibiotic resistance can be used as the basis for selection; for example, dhfr which confers resistance to methotrexate (Wigler et al 1980 Proc Natl Acad Sci 77:3567-70); and npt, which confers resistance to the aminoglycosides neomycin and G-418 10 (Colbere-Garapin et al 1981 J Mol Biol 150:1-14). Additional selectable genes have been described, for example, trpB, which allows cells to utilize indole in place of tryptophan, or hisD, which allows cells to utilize histinol in place of histidine (Hartman et al. 1988 Proc Natl Acad Sci 85:8047-51). Selectable markers also include visible markers such as anthocyanins, β -glucuronidase and its substrate, GUS, 15 and luciferase and its substrate, luciferin. Such visible markers are useful to both identify transformants and to quantify the amount of transient or stable protein expression attributable to a specific vector system (Rhodes et al 1995 Methods Mol Biol 55:121-131).

Alternatively, host cells that contain the coding sequence for and express capsaicin receptor polypeptides and/or capsaicin receptor-related polypeptides can be identified by a variety of procedures known to those of skill in the art. These procedures include, but are not limited to, DNA-DNA or 20 DNA-RNA hybridization and protein bioassay or immunoassay techniques for the detection and/or quantitation of the nucleic acid or protein.

The presence of polynucleotide sequences encoding a capsaicin receptor and/or capsaicin receptor-related polypeptide can be detected by DNA-DNA or DNA-RNA hybridization or PCR amplification using probes, portions or fragments of polynucleotides encoding capsaicin receptor and/or 25 capsaicin receptor-related polypeptide. Nucleic acid amplification-based assays involve the use of oligonucleotides or oligomers based on a sequence encoding a capsaicin receptor or capsaicin receptor-related polypeptide to detect transformants containing the desired DNA or RNA. As used herein "oligonucleotides" or "oligomers" refer to a nucleic acid sequence of at least about 10 nucleotides and as many as about 60 nucleotides, preferably about 15 to 30 nucleotides, and more preferably about 30 20-25 nucleotides which can be used as a probe or amplimer.

A variety of immunoassays for detecting and measuring the expression of a specific protein, using either protein-specific polyclonal or monoclonal antibodies are known in the art. Examples include enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA) and fluorescent activated cell sorting (FACS). These and other assays are described in, e.g., Hampton et al 1990, Serological 35 Methods, A Laboratory Manual, APS Press, St Paul MN and Maddox et al 1983, J Exp Med 158:1211.

A wide variety of detectable labels and conjugation techniques are known the art and can be used in various nucleic acid and amino acid assays. Means for producing labeled hybridization or PCR probes for detecting sequences related to sequences encoding a capsaicin receptor or capsaicin

receptor-related polypeptide include oligolabeling, nick translation, end-labeling or PCR amplification using a labeled nucleotide. Alternatively, a nucleotide sequence encoding a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide can be cloned into a vector for the production of an mRNA probe. Vectors and methods for production of mRNA probes are well known in the art.

5 Suitable reporter molecules or labels include those radionuclides, enzymes, fluorescent, chemiluminescent, or chromogenic agents as well as substrates, cofactors, inhibitors, magnetic particles and the like, as described in U.S. Patent Nos. 3,817,837; 3,850,752; 3,939,350; 3,996,345; 4,277,437; 4,275,149 and 4,366,241, each of which are incorporated herein by reference.

In a preferred embodiment, host cells expressing capsaicin receptor are screened and selected 10 using a functional assay for capsaicin receptor activity. For example, host cells expressing functional capsaicin receptor can be screened for alterations in intracellular calcium concentrations upon exposure to a capsaicin receptor binding compound (e.g., capsaicin or resiniferatoxin). Where the capsaicin receptor binding compound is a capsaicin receptor agonist, binding of the agonist compound to the capsaicin receptor result in increased levels of intracellular calcium in the host cell expressing capsaicin 15 receptor-encoding nucleic acid. Methods and compositions (e.g., fura-2) for monitoring intracellular calcium concentration are well known in the art.

Purification of Capsaicin Receptor Polypeptides and Capsaicin Receptor-Related Polypeptides

Methods for production of a polypeptide after identification of its encoding polynucleotide are 20 well known in the art. Host cells transformed with a nucleotide sequence(s) encoding a capsaicin receptor polypeptide and/or capsaicin receptor-related polypeptide-can be cultured under conditions suitable for the expression and recovery of the encoded polypeptide from cell culture. The polypeptide produced by a recombinant cell may be secreted or retained intracellularly depending on the sequence and/or the vector used. As will be understood by those of skill in the art, expression vectors containing 25 polynucleotides encoding capsaicin receptor polypeptides or capsaicin receptor-related polypeptides can be designed with signal sequences that direct secretion of the encoded polypeptide(s) through a prokaryotic or eukaryotic cell membrane.

Purification of capsaicin receptor polypeptides and capsaicin receptor-related polypeptides can be facilitated by using a recombinant construct that includes a nucleotide sequence(s) encoding one 30 or more polypeptide domains that, when expressed in-frame with the sequence encoding the capsaicin receptor or capsaicin receptor-related polypeptide, provides a fusion protein having a purification-facilitating domain (Kroll et al 1993 DNA Cell Biol 12:441-53). A cleavable linker sequences(s) between the purification domain and the capsaicin receptor polypeptide- or capsaicin receptor-related polypeptide-encoding sequence can be included to further facilitate purification.

35 Capsaicin receptor polypeptides and capsaicin receptor-related polypeptides (each of which polypeptides encompass polypeptides having a portion of the native amino acid sequence) can also be produced by direct peptide synthesis using solid-phase techniques (see, e.g., Stewart et al 1969 Solid-Phase Peptide Synthesis, WH Freeman Co, San Francisco; Merrifield 1963 J Am Chem Soc

85:2149-2154). Various fragments of capsaicin receptor or capsaicin receptor-related polypeptide can be chemically synthesized separately and combined using chemical methods to produce the full length molecule.

Methods for purifying a desired polypeptide following either artificial synthesis or recombinant 5 production are routine and well known in the art.

Uses of Capsaicin Receptor Polypeptides, Capsaicin Receptor-Related Polypeptides, and Nucleic Acid Encoding Capsaicin Receptor Polypeptides or Capsaicin Receptor-Related Polypeptides

In addition to the uses described above, the nucleotide and polypeptide sequences disclosed 10 herein can be used in a variety of ways, including production of antibodies, identification of capsaicin receptor-binding compounds and capsaicin receptor-related polypeptide-binding compounds that affect capsaicin receptor function (e.g., in a drug screening assay), and in the identification of other polynucleotide sequences encoding capsaicin receptor polypeptides and capsaicin receptor-related polypeptides. In addition, sequences encoding capsaicin receptor polypeptides and capsaicin receptor-related polypeptides can be used in diagnostic assays (e.g., prenatal or postnatal diagnosis). Furthermore, capsaicin receptor-encoding sequences and their encoded polypeptides can also be used 15 in assays to assess the capsaicin content of a sample (e.g., from a natural product, e.g., a chili pepper extract) or the capsaicin-promoting effects of an agent (e.g., a candidate agent for use as a flavor enhancing additive to foods).

20 These and other applications of the sequences of the invention are described in more detail below.

Screening for Capsaicin Receptor- and Capsaicin Receptor-Related Polypeptide Binding Compounds

25 Capsaicin receptor polypeptides and capsaicin receptor-related polypeptides, each of which encompasses biologically active or immunogenic fragments or oligopeptides thereof, can be used for screening compounds that affect capsaicin receptor activity by, for example, specifically binding capsaicin receptor and affecting its function or specifically binding capsaicin receptor-related polypeptide and affecting its interaction with capsaicin receptor, thereby affecting capsaicin receptor activity. Identification of such compounds can be accomplished using any of a variety of drug screening 30 techniques. Of particular interest is the identification of agents that have activity in affecting capsaicin receptor function. Such agents are candidates for development of treatments for, inflammatory conditions associated at least in part with capsaicin receptor activity (e.g., psoriasis, reactive airway diseases (e.g., asthma, chronic obstructive pulmonary disease)), arthritis (e.g., osteoarthritis, rheumatoid arthritis), and for use as analgesics. Of particular interest are screening assays for agents 35 that have a low toxicity for human cells. The polypeptide employed in such a test can be free in solution, affixed to a solid support, present on a cell surface, or located intracellularly. The screening assays of the invention are generally based upon the ability of the agent to bind to a capsaicin receptor polypeptide, bind to a capsaicin receptor-related polypeptide, and/or elicit or inhibit a capsaicin receptor-

associated or capsaicin receptor-related polypeptide-associated biological activity (i.e., a functional assay or an assay using radioligand binding assays).

The term "agent" as used herein describes any molecule, e.g. protein or pharmaceutical, with the capability of altering (i.e., eliciting or inhibiting) or mimicking a desired physiological function of 5 capsaicin receptor or capsaicin receptor-related polypeptide. Generally a plurality of assay mixtures are run in parallel with different agent concentrations to obtain a differential response to the various concentrations. Typically, one of these concentrations serves as a negative control, i.e. at zero concentration or below the level of detection.

Candidate agents encompass numerous chemical classes, though typically they are organic 10 molecules, preferably small organic compounds having a molecular weight of more than 50 and less than about 2,500 daltons. Candidate agents comprise functional groups necessary for structural interaction with proteins, particularly hydrogen bonding, and typically include at least an amine, carbonyl, hydroxyl or carboxyl group, preferably at least two of the functional chemical groups. The candidate agents often comprise cyclical carbon or heterocyclic structures and/or aromatic or 15 polyaromatic structures substituted with one or more of the above functional groups. Candidate agents are also found among biomolecules including, but not limited to: peptides, saccharides, fatty acids, steroids, purines, pyrimidines, derivatives, structural analogs or combinations thereof.

Candidate agents are obtained from a wide variety of sources including libraries of synthetic or natural compounds. For example, numerous means are available for random and directed synthesis 20 of a wide variety of organic compounds and biomolecules, including expression of randomized oligonucleotides and oligopeptides. Alternatively, libraries of natural compounds in the form of bacterial, fungal, plant and animal extracts (including extracts from human tissue to identify endogenous factors affecting capsaicin receptor or capsaicin receptor-related polypeptide activity) are available or readily produced. Additionally, natural or synthetically produced libraries and compounds are readily modified 25 through conventional chemical, physical and biochemical means, and may be used to produce combinatorial libraries. Known pharmacological agents may be subjected to directed or random chemical modifications, such as acylation, alkylation, esterification, amidification, etc. to produce structural analogs.

Preferably, the drug screening technique used provides for high throughput screening of 30 compounds having suitable binding affinity to the capsaicin receptor, capsaicin receptor-related polypeptide, and/or eliciting a desired capsaicin receptor-associated or capsaicin receptor-related polypeptide-associated response. For example, large numbers of different small peptide test compounds can be synthesized on a solid substrate, such as plastic pins or some other surface (see, e.g., Geysen WO Application 84/03564, published on September 13, 1984), the peptide test compounds 35 contacted with capsaicin receptor polypeptides (or capsaicin receptor-related polypeptides), unreacted materials washed away, and bound capsaicin receptor (or bound capsaicin receptor-related polypeptide) detected by virtue of a detectable label or detection of a biological activity associated with capsaicin receptor activity (or capsaicin receptor-related polypeptide activity). Purified capsaicin

receptor or purified capsaicin receptor-related polypeptide can also be coated directly onto plates for use in such *in vitro* drug screening techniques. Alternatively, non-neutralizing antibodies can be used to capture the polypeptide and immobilize it on a solid support.

The invention also contemplates the use of competitive drug screening assays in which 5 capsaicin receptor-specific neutralizing antibodies or capsaicin receptor-related polypeptide-specific neutralizing antibodies compete with a test compound for binding of capsaicin receptor polypeptide or capsaicin receptor-related polypeptide. In this manner, the antibodies can be used to detect the presence of any polypeptide that shares one or more antigenic determinants with a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide.

10 Screening of Candidate Agents

A wide variety of assays may be used for identification of capsaicin receptor polypeptide and/or capsaicin receptor-related polypeptide binding agents, including labeled *in vitro* binding assays, immunoassays for protein binding, and the like. For example, by providing for the production of large amounts of capsaicin receptor polypeptides or capsaicin receptor-related polypeptides, one can identify 15 ligands or substrates that bind to, modulate or mimic the action of the proteins. The purified protein may also be used for determination of three-dimensional crystal structure, which can be used for modeling intermolecular interactions.

The screening assay can be a binding assay, wherein one or more of the molecules may be joined to a label, and the label directly or indirectly provide a detectable signal. Various labels include 20 radioisotopes, fluorescers, chemiluminescers, enzymes, specific binding molecules, particles, e.g. magnetic particles, and the like. Specific binding molecules include pairs, such as biotin and streptavidin, digoxin and antidigoxin etc. For the specific binding members, the complementary member would normally be labeled with a molecule that provides for detection, in accordance with known procedures.

25 A variety of other reagents may be included in the screening assays described herein. Where the assay is a binding assay, these include reagents like salts, neutral proteins, e.g. albumin, detergents, etc that are used to facilitate optimal protein-protein binding, protein-DNA binding, and/or reduce non-specific or background interactions. Reagents that improve the efficiency of the assay, such as protease inhibitors, nuclease inhibitors, anti-microbial agents, etc. may be used. The mixture of 30 components are added in any order that provides for the requisite binding. Incubations are performed at any suitable temperature, typically between 4 and 40°C. Incubation periods are selected for optimum activity, but may also be optimized to facilitate rapid high-throughput screening. Typically between 0.1 and 1 hours will be sufficient.

Functional Capsaicin Receptor and Capsaicin Receptor-Related Polypeptide Screening Assays

35 Preferably, capsaicin receptor-binding compounds are screened for agonistic or antagonist action in a functional assay that monitors a biological activity associated with capsaicin receptor function such as effects upon intracellular levels of cations in a capsaicin receptor-expressing host cell (e.g., calcium, magnesium, guanidinium, cobalt, potassium, cesium, sodium, and choline, preferably calcium),

ligand-activated conductances, cell death (i.e., receptor-mediated cell death which can be monitored using, e.g., morphological assays, chemical assays, or immunological assays), depolarization of the capsaicin receptor-expressing cells (e.g., using fluorescent voltage-sensitive dyes), second messenger production (e.g., through detection of changes in cyclic GMP levels (see, e.g., Wood et al. 1989 J. 5 Neurochem. 53:1203-1211), which can be detected by radioimmunoassay or ELISA), calcium-induced reporter gene expression (see, e.g., Ginty 1997 Neuron 18:183-186), or other readily assayable biological activity associated with capsaicin receptor activity or inhibition of capsaicin receptor activity. 10 Preferably, the functional assay is based upon detection of a biological activity of capsaicin receptor that can be assayed using high-throughput screening of multiple samples simultaneously, e.g., a functional assay based upon detection of a change in fluorescence which in turn is associated with a 15 change in capsaicin receptor activity. Such functional assays can be used to screen candidate agents for activity as either capsaicin receptor agonists or antagonists.

In a preferred embodiment, capsaicin receptor-expressing cells (preferably recombinant capsaicin receptor-expressing cells) are pre-loaded with fluorescently-labeled calcium (e.g., fura-2). The 15 capsaicin receptor-expressing cells are then exposed to a candidate capsaicin receptor-binding compound and the effect of exposure to the compound monitored. Candidate compounds that have capsaicin receptor agonist activity are those that, when contacted with the capsaicin receptor-expressing cells, elicit a capsaicin receptor-mediated increase in intracellular calcium relative to control 20 cells (e.g., capsaicin receptor-expressing cells in the absence of the candidate compound, host cells without capsaicin receptor-encoding nucleic acid, capsaicin receptor-expressing cells exposed to a known capsaicin receptor agonist). Similarly, functional capsaicin receptor assays can be used to identify candidate compounds that block activity of a known capsaicin receptor agonist (e.g., block the 25 activity of or compete with capsaicin or resiniferatoxin), block activity of a known capsaicin receptor antagonist (e.g., block the activity of or compete with capsazepine), and/or have activity as capsaicin receptor antagonists.

In another embodiment, the invention includes a method for identifying compounds that bind capsaicin receptor-related polypeptide, thereby eliciting an agonistic or antagonistic effect on capsaicin receptor-associated function as detected by e.g., intracellular levels of cations in the host cell. To this end, the functional assay involves contacting host cells expressing a capsaicin receptor alone (e.g., 30 VR1) and with host cell co-expressing a capsaicin receptor and a capsaicin receptor-related polypeptide (e.g., VR1 and VRRP-1). Compounds that affect capsaicin receptor activity by affecting function of a capsaicin receptor-related polypeptide are those that affect a capsaicin receptor-associated activity in cells that co-express capsaicin receptor and capsaicin receptor-related polypeptide, but do not significantly affect capsaicin receptor-associated activity in host cells that express capsaicin receptor 35 alone. For example, compounds that elicit a capsaicin receptor-mediated increase in intracellular calcium in cells co-expressing capsaicin receptor and capsaicin receptor-related polypeptide, but not in cells expressing capsaicin receptor alone, are identified as compounds that elicit capsaicin receptor agonist activity via interaction with a capsaicin receptor-related polypeptide.

Pharmaceutical Compositions and Other Compositions Comprising Agents Affecting Capsaicin Receptor Activity Identified by the Screening Assay of the Invention

Capsaicin receptor-binding compounds and capsaicin receptor-related polypeptide-binding compounds are useful in eliciting or inhibiting capsaicin receptor-mediated physiological responses, and

5 can be particularly useful in a pharmaceutical composition for ameliorating symptoms associated with chronic pain, inflammation, and other physiological responses associated with capsaicin receptor-mediated activity.

The compounds having the desired pharmacological activity may be administered in a physiologically acceptable carrier to a host for treatment of a condition attributable to capsaicin receptor activity. Alternatively, the identified compounds may be used to enhance, regulate, or otherwise manipulate capsaicin receptor function. The therapeutic agents may be administered in a variety of ways, topically, subcutaneously, intraperitoneally, intravascularly, orally, intrathecally, epidermally, intravesicularly (e.g., as in bladder irrigation to treat neurogenic bladder syndromes), parenterally, etc. Inhaled treatments are of particular interest for the treatment of capsaicin receptor-associated inflammation associated with such conditions as asthma.

Depending upon the manner of introduction, the compounds may be formulated in a variety of ways. The concentration of therapeutically active compound in the formulation may vary from about 0.1-100 wt.%. The pharmaceutical compositions can be prepared in various forms, such as granules, tablets, pills, capsules, suspensions, salves, lotions and the like. Pharmaceutical grade organic or inorganic carriers and/or diluents suitable for the selected route of administration can be used to make up compositions containing the therapeutically-active compounds. Diluents known to the art include aqueous media, vegetable and animal oils and fats. Stabilizing agents, wetting and emulsifying agents, salts for varying the osmotic pressure or buffers for securing an adequate pH value, and skin penetration enhancers can be used as auxiliary agents.

25 In addition, compositions comprising agents affecting capsaicin receptor activity (e.g., by binding capsaicin receptor or by binding a capsaicin receptor-related polypeptide) are useful in other applications, including use in defensive sprays (e.g., "pepper sprays") or as antidotes for such sprays.

The screening methods of the invention can be used in a variety of ways to this end, including, for example, identification of drugs that have capsaicin-like activity, but lack or are substantially diminished

30 in one or more of the undesirable side effects associated with capsaicin. For example, while capsaicin is effective in spray deterrents, exposure to capsaicin can be lethal. The screening method of the invention can thus be used to identify compounds that have the desired deterrent effect, but would not likely cause death upon exposure to amounts normally used in defensive sprays. Moreover, the screening method of the invention could be used to identify compounds that differentially affect

35 capsaicin receptors of different mammalian species, thus enabling identification and design of capsaicin receptor agonists and antagonists that substantially affect capsaicin receptors with genus- or species-specificity. Thus, for example, the method of the invention can allow for identification of capsaicin receptor agonists for canine or bear capsaicin receptors, but that do not substantially stimulate human

capsaicin receptors. This could be accomplished by screening for compounds that elicit a capsaicin receptor-associated biological activity in host cells expressing a canine capsaicin receptor, but relatively little or no biological activity in host cells expressing human capsaicin receptor.

Therapeutically Effective Dosages

5 The determination of an effective dose is well within the capability of those skilled in the art. For any compound, the therapeutically effective dose can be estimated initially either in cell culture assays, e.g., using host cells expressing recombinant capsaicin receptor, or in animal models, usually rats, mice, rabbits, dogs, or pigs. The animal model is also used to achieve a desirable concentration range and route of administration. Such information can then be used to determine useful doses and routes for 10 administration in humans. A therapeutically effective dose refers to that amount of an agent (e.g., a compound having activity as capsaicin receptor agonist or antagonist), polypeptide, or anti-polypeptide antibody, that provide the desired physiological effect (e.g., to ameliorate symptoms associated with capsaicin receptor-mediated inflammation or pain, or provide loss of temperature sensation).

15 Therapeutic efficacy and toxicity of such compounds can be determined by standard pharmaceutical procedures in cell cultures or experimental animals, e.g., ED50 (the dose therapeutically effective in 50% of the population) and LD50 (the dose lethal to 50% of the population). The dose ratio between therapeutic and toxic effects is the therapeutic index, and expressed as the ratio LD50/ED50. Pharmaceutical compositions that exhibit large therapeutic indices are preferred. The data obtained from cell culture assays and animal studies is used in formulating a range of dosage for human use. 20 The dosage of such compounds lies preferably within a range of circulating concentrations that include the ED50 with little or no toxicity. The actual dosage can vary within this range depending upon, for example, the dosage form employed, sensitivity of the patient, and the route of administration.

25 The exact dosage is chosen by the individual physician in view of the patient to be treated. Dosage and administration are adjusted to provide sufficient levels of the active moiety or to maintain the desired effect. Additional factors that may be taken into account include the severity of the disease state, location of the site to be treated; age, weight and gender of the patient; diet, time and frequency of administration; drug combination(s); reaction sensitivities; and tolerance/response to therapy. Long-acting pharmaceutical compositions can be administered every 3 to 4 days, every week, or once every two weeks depending on half-life and clearance rate of the particular formulation.

30 Normal dosage amounts may vary depending upon the route of administration. Guidance as to particular dosages and methods of delivery is provided in the literature and generally available to practitioners in the art. Use of capsaicin and capsaicin analogues in clinical applications and their methods of administration (e.g., formulations, dosages, routes of administration, etc.) are well known in the art (see, e.g., Campbell et al. 1993 "Clinical Applications of Capsaicin and Its Analogues," in 35 Capsaicin in the Study of Pain, pgs. 255-272; USPN 5,5690,910 (topical anti-inflammatory compositions comprising capsaicin); USPN 5,296,225 (topical composition comprising capsaicin for treating orofacial pain); USPN 5,290,816 (topical cream containing resiniferatoxin for desensitization of neurogenic inflammation); USPN 4,997,853 (topical composition containing capsaicin for treating superficial pain);

USPN 5,403,868 (capsaicin derivatives useful as analgesic and anti-inflammatory agents); USPN 4,939,149 (administration of resiniferatoxin to cause sensory afferent C-fibre and thermo-regulatory desensitization); USPN 4,536,404 (topical treatment of post herpetic neuralgia by application of capsaicin), each of which is incorporated by reference in its entirety. Further general guidance on 5 administration of capsaicin receptor agonist and antagonists can be found in, e.g., United States Pharmacopeia (USP), 17th Ed., pgs. 710-711; and Physician's Desk Reference 1996, Medical Economics Com., Montvale, NJ (see particularly DoloracTM at 1054, ZostrixTM at 1056, and Zostrix-HPTM topical analgesic cream at 1056, each of which contain capsaicin); and the latest edition of Remingtons' Pharmaceutical Sciences, Mack Publishing Co., Easton PA.

10 Use of Capsaicin Receptor-Encoding Polynucleotides in Assays for Quantitating the Capsaicin Content of a Sample or Determining the Capsaicin Activity of a Candidate Food Additive

15 Capsaicin receptor polypeptide-encoding polynucleotides and capsaicin receptor polypeptides can be used in an assay to determine, either qualitatively or quantitatively, to detect capsaicin or an agent having capsaicin activity, in a sample, where the sample is derived from a food product or contains a candidate agent for use as a flavoring agent (e.g., for use as a spice in food or food products).

20 This assay takes advantage of the fact that, in addition to its analgesic effects upon afferent neurons, capsaicin is a member of the vanilloid family of compounds, which are responsible for making foods "spicy hot." For example, capsaicin is present in peppers (e.g., Thai, green poblano verde, habenero, and guero peppers). Conventional assays for determining the amount of capsaicin in a pepper extract involve tedious extraction of the compound from pepper samples and quantitation by high pressure 25 liquid chromatography (HPLC) (see, e.g., Woodbury 1980 J. Assoc. Off. Anal. Chem. 63:556-558). The amount of capsaicin is then correlated with number of Scoville heat units, a measure of "hotness."

25 The assay of the invention uses an isolated capsaicin receptor polypeptide to detect the amount of capsaicin in a sample, thus avoiding the chemical extraction technique employed in the conditional assay. The capsaicin receptor polypeptide used may be either bound to a solid support, present in solution, or present on the surface of a recombinant host cell. Binding of capsaicin to the capsaicin receptor polypeptide is detected as described in the screening assays described above.

30 Preferably, the assay for capsaicin or a compound having capsaicin activity in a sample is performed using a functional assay described above. More preferably, the functional assay uses capsaicin receptor-expressing recombinant eukaryotic cells (preferably mammalian cells or amphibian oocytes) that are preloaded with a calcium-sensitive fluorescent dye (e.g., fura-2, indo-1, fluo-3). The presence and/or amount of capsaicin or capsaicinoid compound in the sample is then determined by measuring a capsaicin receptor-mediated cellular effect, e.g., an alteration in voltage-activated 35 conductances across the cellular membrane or an alteration in the intracellular levels of the detectably labeled cation. For example, where the detectably labeled cation is fluorescently labeled calcium, exposure of the pre-loaded host cells to a capsaicin-containing sample results in binding of the capsaicin to the capsaicin receptor polypeptide and the capsaicin receptor-mediated increase in intracellular calcium, which can be readily detected and quantitated. For example, the level of

intracellular calcium influx mediated by the test sample is compared to the intracellular calcium influx associated with a control sample (e.g., with a sample having a known amount of capsaicin). The extent of the change in current, intracellular calcium concentration, or other capsaicin receptor-mediated phenomenon is then correlated with a concentration of capsaicin, which in turn can be assigned a

5 Scoville heat unit.

Similarly, candidate agents for use as food additives to make a food or food product "hot" can be screened for their ability to elicit a capsaicin receptor-mediated cellular response (e.g., change in voltage-activated conductances or intracellular cation concentration). The assay has the advantage that the measure of hotness can be determined objectively, e.g., based upon the responses elicited by

10 exposure to the capsaicin receptor.

Diagnostic Uses of Polynucleotides Encoding Capsaicin Receptor or Capsaicin Receptor-Related Polypeptides to Detect Capsaicin Receptor-Encoding Sequences

Polynucleotide sequences encoding capsaicin receptor polypeptide or capsaicin receptor-related polypeptide can be used in the diagnosis (e.g., prenatal or post-natal diagnosis) of conditions or diseases associated with, for example, capsaicin receptor expression, with a particular capsaicin receptor polymorphism or mutation, and/or with capsaicin receptor-related polypeptide expression. For example, polynucleotide sequences encoding capsaicin receptor or capsaicin receptor-related polypeptide can be used in hybridization or PCR assays of fluids or tissues from biopsies to detect capsaicin receptor or capsaicin receptor-related polypeptide expression, respectively. Suitable qualitative or quantitative methods include Southern or northern analysis, dot blot or other membrane-based technologies; PCR technologies; dip stick, pIN, chip and ELISA technologies. All of these techniques are well known in the art and are the basis of many commercially available diagnostic kits. Once disease is established, a therapeutic agent is administered or other intervention or precautions initiated as appropriate for the capsaicin receptor-associated disorder.

25 Oligonucleotides based upon capsaicin receptor or capsaicin receptor-related polypeptide sequences can be used in PCR-based techniques for assessing capsaicin receptor-polypeptide expression, detection of capsaicin receptor polymorphisms associated with disorders, and/or capsaicin receptor-related polypeptide expression. Methods for PCR amplification are described in U.S. Patent Nos. 4,683,195 and 4,965,188. Such oligomers are generally chemically synthesized, or produced 30 enzymatically or by recombinantly. Oligomers generally comprise two nucleotide sequences, one with sense orientation (5'->3') and one with antisense (3'<-5'), employed under optimized conditions for identification of a specific gene or condition. The same two oligomers, nested sets of oligomers, or even a degenerate pool of oligomers can be employed under less stringent conditions for detection and/or quantitation of closely related DNA or RNA sequences.

35 Additional methods for quantitation of expression of a particular molecule according to the invention include radiolabeling (Melby et al 1993 J Immunol Methods 159:235-44) or biotinylation (Duplaa C 1993 Anal Biochem 229:36) nucleotides, coamplification of a control nucleic acid, and interpolation of experimental results according to standard curves. Quantitation of multiple samples can

be made more time efficient by running the assay in an ELISA format in which the oligomer of interest is presented in various dilutions and rapid quantitation is accomplished by spectrophotometric or colorimetric detection.

Therapeutic Uses of Capsaicin Receptor Polypeptides and Capsaicin Receptor Polypeptide- Encoding Nucleic Acid

10 Polypeptides of, as well as nucleotide sequence encoding, capsaicin receptor polypeptides and capsaicin receptor-related polypeptides may be useful in the treatment of conditions associated with capsaicin receptor dysfunction (e.g., capsaicin receptor activity that is increased relative to capsaicin receptor activity in an unaffected patient or capsaicin receptor activity that is decreased relative to capsaicin receptor activity in an unaffected patient). In addition, expression of dominant-negative capsaicin receptor-encoding sequences may be therapeutically useful in a condition associated with elevated levels of capsaicin receptor activity. Where interaction of capsaicin receptor and a capsaicin receptor-related polypeptide is associated with a condition, interaction of these polypeptides can be disrupted by, for example, introduction of a peptide corresponding to an interaction domain of capsaicin receptor and capsaicin receptor-related polypeptide. Moreover, expression of a wild-type capsaicin receptor sequence in tumor cells may render such tumor cells more susceptible to capsaicin receptor-mediated cell death.

Expression vectors derived from retroviruses, adenovirus, herpes or vaccinia viruses, or from various bacterial plasmids, can be used for delivery of nucleotide sequences to the targeted organ, tissue or cell population. Preferably the targeted cell for delivery and expression of capsaicin receptor polypeptide-encoding sequences is a neuronal cell, more preferably an afferent neuron in order to enhance capsaicin receptor activity in the neuronal cell. Recombinant vectors for expression of antisense capsaicin receptor polynucleotides can be constructed according to methods well known in the art (see, for example, the techniques described in Sambrook et al (supra) and Ausubel et al (supra)).

25 Alternatively, expression of genes encoding capsaicin receptor can be decreased by
transfected a cell or tissue with expression vectors that express high levels of a desired capsaicin
receptor-encoding fragment. Such constructs can flood cells with untranslatable sense or antisense
sequences. Even in the absence of integration into the DNA, such vectors can continue to transcribe
RNA molecules until all copies are disabled by endogenous nucleases. Such an approach to regulation
30 of capsaicin receptor expression and activity can be useful in treatment of pain syndromes and/or
inflammatory conditions associated with capsaicin receptor activity.

Modifications of gene expression can be obtained by designing antisense molecules, DNA, RNA or PNA, to the control regions of gene encoding capsaicin receptor (i.e., the promoters, enhancers, and introns). Oligonucleotides derived from the transcription initiation site, e.g., between -10 and +10 regions of the leader sequence, are preferred. The antisense molecules can also be designed to block translation of mRNA by preventing the transcript from binding to ribosomes. Similarly, inhibition of expression can be achieved using "triple helix" base-pairing methodology. Triple helix pairing compromises the ability of the double helix to open sufficiently for binding of polymerases, transcription

5 factors, or regulatory molecules. Recent therapeutic advances using triplex DNA were reviewed by Gee JE et al (In: Huber et al. 1994 Molecular and Immunologic Approaches, Futura Publishing Co, Mt Kisco NY). Antisense molecules of the invention can be prepared by methods known in the art for the synthesis of RNA molecules, including techniques for chemical oligonucleotide synthesis, e.g., solid phase phosphoramidite chemical synthesis. Such DNA sequences can be incorporated into a wide variety of vectors with suitable RNA polymerase promoters (e.g., T7 or SP6). Alternatively, antisense cDNA constructs useful in the constitutive or inducible synthesis of antisense RNA can be introduced into cell lines, cells, or tissues.

10 Particularly where RNA molecules are to be administered for antisense therapy, the RNA can be modified to increase intracellular stability and half-life. Possible modifications include, but are not limited to, the addition of flanking sequences at the 5' and/or 3' ends of the molecule, or the use of phosphorothioate or 2' O-methyl rather than phosphodiesterase linkages within the backbone of the molecule. This concept is inherent in the production of PNAs and can be extended in all of these molecules by the inclusion of nontraditional bases such as inosine, queosine and wybutosine as well 15 as acetyl-, methyl-, thio- and similarly modified forms of adenine, cytidine, guanine, thymine, and uridine that are not as easily recognized by endogenous endonucleases.

Methods for introducing vectors into cells or tissues include those methods discussed infra and which are equally suitable for in vivo therapy.

20 In a preferred embodiment, capsaicin receptor polypeptide-encoding polynucleotides are introduced in vivo into a target tumor cell for which organochemotherapy is desired. This aspect of the invention takes advantage of the range of capsaicin receptor response to exposure to agonists (e.g., capsaicin, resiniferatoxin) and/or to temperature. For example, low concentrations of capsaicin receptor agonists (e.g., capsaicin receptor agonist concentrations in the nanomolar range, e.g., from about 200 nM to about 800 nM) are associated with capsaicin receptor stimulation and intracellular calcium influx.

25 Where the capsaicin receptor is expressed in a neuronal cell, capsaicin receptor stimulation by low concentrations of capsaicin receptor agonist is followed by neuronal desensitization. However, high concentrations of capsaicin receptor agonists (e.g., capsaicin receptor agonist concentrations in the micromolar range, e.g., from about 1 μ M to about 10 μ M) mediate neuronal degeneration and cell death.

30 By expressing capsaicin receptor polypeptides in tumor cells, the tumor cell death can be substantially selectively facilitated by local administration of high concentrations of a capsaicin receptor agonist, or by local exposure to heat stimuli, or both, where the agonist concentration and/or heat stimulus is sufficient to mediate cell death in the capsaicin receptor-expressing target tumor cell, but does not substantially affect normal capsaicin receptor-expressing cells or affects a minimal number of such normal cells.

35 Alternatively, the capsaicin receptor polypeptide introduced into the tumor cells can be engineered to provide more selectivity in the response to organochemotherapy (i.e., to provide for activation of the capsaicin receptor expressed in the tumor cells with no or little activation of endogenous, wild-type capsaicin receptor). For example, capsaicin receptor can be modified so as to

bind a specific capsaicin receptor agonist analogue, which analogue is substantially reduced in its ability to bind wildtype capsaicin receptors. Therefore, target cells (e.g., tumor cells) expressing the altered capsaicin receptor can be selectively stimulated by administration of the agonist having specificity for the altered capsaicin receptor polypeptide without substantially affecting cells expressing wildtype 5 capsaicin receptor. Alternatively, the tumor cells can be transformed *in vivo* with a sequence encoding a modified capsaicin receptor, where the modified capsaicin receptor is more responsive to agonists (e.g., is more responsive to agonist, has increased affinity to agonists relative to wild-type thereby allowing activation of the modified receptors with no or little activation of the endogenous capsaicin receptor, and/or is modified so as to be more responsive to heat stimuli than wild-type capsaicin 10 receptor). These embodiments thus allow administration of high or higher concentrations of the altered capsaicin receptor-targeted organochemotherapeutic, thereby providing for more selective organochemotherapy.

Anti-Capsaicin Receptor and Anti-Capsaicin Receptor-Related Polypeptide Antibodies

15 Capsaicin receptor-specific antibodies and capsaicin receptor-related polypeptide-specific antibodies are useful for identification of cells expressing either naturally-occurring or recombinant capsaicin receptor polypeptides or capsaicin receptor-related polypeptides, respectively, as well as the diagnosis of conditions and diseases associated with expression and/or function of capsaicin receptor and/or capsaicin receptor-related polypeptides. For example, anti-capsaicin receptor antibodies and 20 anti-capsaicin receptor-related polypeptide antibodies can be used to detect increased or decreased receptor protein levels, and/or aberrant protein processing or oligomerization.

25 Anti-capsaicin receptor polypeptide antibodies and anti-capsaicin receptor-related polypeptide antibodies of the invention include, but are not limited to, polyclonal, monoclonal, chimeric, single chain, Fab fragments and fragments produced by a Fab expression library. Antibodies of particular interest include, for example, antibodies that stimulate capsaicin receptor function and/or block binding of 30 capsaicin receptor-binding compounds to capsaicin receptor. Such antibodies may be useful in, for example, regulation of pain in pain syndromes, in screening assays for capsaicin receptor-binding agents, and in measurement of capsaicin receptor-activating compounds in a sample.

30 Capsaicin receptor polypeptides and capsaicin receptor-related polypeptides suitable for production of antibodies need not be biologically active; rather, the polypeptide, or oligopeptide need only be antigenic. Polypeptides used to generate capsaicin receptor-specific antibodies and capsaicin receptor-related polypeptide antibodies generally have an amino acid sequence consisting of at least five amino acids, preferably at least 10 amino acids. Preferably, antigenic capsaicin receptor polypeptides and antigenic capsaicin receptor-related polypeptides mimic an epitope of the native 35 capsaicin receptor or native capsaicin receptor-related polypeptide, respectively. Antibodies specific for short polypeptides can be generated by linking the capsaicin receptor polypeptide or capsaicin receptor-related polypeptide to a carrier, or fusing the capsaicin receptor polypeptide or capsaicin receptor-related polypeptide to another protein (e.g., keyhole limpet hemocyanin), and using the carrier-

linked chimeric molecule as an antigen. In general, anti-capsaicin receptor antibodies and capsaicin receptor-related polypeptide antibodies can be produced according to methods well known in the art. Recombinant immunoglobulins can be produced as according to U.S. Patent No. 4,816,567, incorporated herein by reference.

5 Various hosts, generally mammalian or amphibian hosts, can be used to produce anti-capsaicin receptor antibodies and anti-capsaicin receptor-related polypeptide antibodies (e.g., goats, rabbits, rats, mice). In general, antibodies are produced by immunizing the host (e.g., by injection) with a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide that retains immunogenic properties (which encompasses any portion of the native polypeptide, fragment or oligopeptide). Depending on
10 the host species, various adjuvants can be used to increase the host's immunological response. Such adjuvants include but are not limited to, Freund's, mineral gels (e.g., aluminum hydroxide), and surface active substances such as lysolecithin, pluronic polyols, polyanions, peptides, oil emulsions, keyhole limpet hemocyanin, and dinitrophenol. BCG (bacilli Calmette-Guerin) and Corynebacterium parvum are potentially useful human adjuvants.

15 Monoclonal antibodies can be prepared using any technique that provides for the production of antibody molecules by immortalized cell lines in culture. These techniques include, but are not limited to, the hybridoma technique originally described by Kohler and Milstein (1975 *Nature* 256:495-497), the human B-cell hybridoma technique (Kosbor et al (1983) *Immunol Today* 4:72; Cote et al (1983) *Proc Natl Acad Sci* 80:2026-2030) and the EBV-hybridoma technique (Cole et al (1985) *Monoclonal Antibodies and Cancer Therapy*, Alan R Liss Inc, New York NY, pp 77-96).

20 In addition, techniques developed for the production of "chimeric antibodies", the splicing of mouse antibody genes to human antibody genes to obtain a molecule with appropriate antigen specificity and biological activity can be used (Morrison et al 1984 *Proc Natl Acad Sci* 81:6851-6855; Neuberger et al 1984 *Nature* 312:604-608; Takeda et al 1985 *Nature* 314:452-454). Alternatively,
25 techniques described for the production of single chain antibodies (U.S. Patent No. 4,946,778) can be adapted to produce single chain antibodies that are capsaicin receptor-specific or capsaicin receptor-related polypeptide-specific.

30 Antibodies can be produced *in vivo* or by screening recombinant immunoglobulin libraries or panels of highly specific binding reagents as disclosed in Orlandi et al (1989, *Proc Natl Acad Sci* 86: 3833-3837), and Winter et al. (1991; *Nature* 349:293-299).

35 Antibody fragments having specific binding sites for a capsaicin receptor polypeptide or capsaicin receptor-related polypeptide can also be generated. For example, such fragments include, but are not limited to, F(ab')2 fragments, which can be produced by pepsin digestion of the antibody molecule, and Fab fragments, which can be generated by reducing the disulfide bridges of the F(ab')2 fragments. Alternatively, Fab expression libraries can be constructed to allow rapid and easy identification of monoclonal Fab fragments with the desired specificity (Huse et al 1989 *Science* 256:1275-1281).

A variety of protocols for competitive binding or immunoradiometric assays using either polyclonal or monoclonal antibodies having established antigen specificities are well known in the art. Such immunoassays typically involve, for example, the formation of complexes between a capsaicin receptor polypeptide and a specific anti-capsaicin receptor antibody, and the detection and quantitation 5 of capsaicin receptor-antibody complex formation. A two-site, monoclonal-based immunoassay utilizing monoclonal antibodies reactive to two noninterfering epitopes on a specific capsaicin receptor protein is preferred, but a competitive binding assay can also be employed. These assays are described in Maddox et al 1983, J Exp Med 158:1211.

Diagnostic Assays Using Capsaicin Receptor-Specific or Capsaicin Receptor-Related 10 Polypeptide-Specific Antibodies

Particular capsaicin receptor antibodies and capsaicin receptor-related polypeptide antibodies are useful for the diagnosis of conditions or diseases characterized by abnormal expression or function of capsaicin receptor (e.g., detection of capsaicin receptor expression in skin to detect neuropathies or in assays to monitor patients having a capsaicin receptor-associated disorder or condition and/or being 15 treated with capsaicin receptor agonists, antagonists, or inhibitors). For example, aberrant carp function might result from over- or under-production of a capsaicin receptor-related polypeptide; thus anti-capsaicin receptor-related antibodies can be used to detect these changes qualitatively or quantitatively. Diagnostic assays for capsaicin receptor or capsaicin receptor-related polypeptide include methods using a detectably-labeled anti-capsaicin receptor antibody or anti-capsaicin receptor-related 20 polypeptide to detect capsaicin receptor in samples (e.g., extracts of cells or tissues). The polypeptides and antibodies of the present invention can be used with or without modification. Frequently, the polypeptides and antibodies are labeled by covalent or noncovalent attachment to a reporter molecule. A wide variety of such suitable reporter molecules are known in the art. Methods for detecting and quantitating antibody binding are well known in the art.

25

Pharmaceutical Compositions Containing Capsaicin Receptor Polypeptides, Capsaicin Receptor-Related Polypeptides, and/or Antibodies Thereto

The present invention also encompasses pharmaceutical compositions that can comprise capsaicin receptor polypeptides, anti-capsaicin receptor polypeptide antibodies, capsaicin receptor-related polypeptides, or anti-capsaicin receptor-related polypeptides, alone or in combination with at 30 least one other agent, such as a stabilizing compound, which can be administered in any sterile, biocompatible pharmaceutical carrier. The pharmaceutical compositions of the invention can be administered to a patient alone or in combination with other agents, drugs or hormones, in pharmaceutical compositions where it is mixed with excipient(s), or with pharmaceutically acceptable 35 carriers. In one embodiment of the present invention, the pharmaceutically acceptable carrier is pharmaceutically inert.

Capsaicin receptor polypeptides and/or capsaicin receptor-related polypeptides can be administered in order to mitigate the effects of, for example, an endogenous factor that acts as a

capsaicin receptor agonist or antagonist or to block or regulate the effects of a capsaicin receptor agonist or antagonist administered to an individual. Anti-capsaicin receptor polypeptide antibodies and/or anti-capsaicin receptor-related polypeptide antibodies can be administered to stimulate a capsaicin receptor in a desired fashion or to block the effects of an endogenous or exogenous capsaicin receptor-binding agonist or antagonist, e.g., via competitive binding to the capsaicin receptor. Pharmaceutical formulations comprising capsaicin receptor polypeptides, capsaicin receptor-related polypeptides, anti-capsaicin receptor antibodies, and/or anti-capsaicin receptor-related polypeptide antibodies can be formulated according to methods known in the art.

10 Transgenic Animals Expressing Polynucleotides Encoding Capsaicin Receptor and/or Capsaicin Receptor-Related Polypeptide-

Nucleic acids encoding capsaicin receptor and/or nucleic acids encoding capsaicin receptor-related polypeptide can be used to generate genetically modified non-human animals or site specific gene modifications in cell lines. The term "transgenic" is intended to encompass genetically modified 15 animals having, for example, a deletion or other knock-out of capsaicin receptor gene activity (and/or capsaicin receptor-related polypeptide activity), an exogenous capsaicin receptor gene (or capsaicin receptor-related polypeptide gene) that is stably transmitted in the host cells, a "knock-in" having altered capsaicin receptor (and/or capsaicin receptor-related polypeptide) gene expression, or an exogenous 20 capsaicin receptor or capsaicin receptor-related polypeptide promoter operably linked to a reporter gene. Of particular interest are homozygous and heterozygous knock-outs and knock-ins of capsaicin receptor and/or capsaicin receptor-related polypeptide function.

Transgenic animals may be made through homologous recombination, where the endogenous capsaicin receptor locus (and/or capsaicin receptor-related polypeptide locus) is altered. Alternatively, a nucleic acid construct is randomly integrated into the genome. Vectors for stable integration include 25 plasmids, retroviruses and other animal viruses, YACs, and the like. Of interest are transgenic mammals, preferably a mammal from a genus selected from the group consisting of *Mus* (e.g., mice), *Rattus* (e.g., rats), *Oryctolagus* (e.g., rabbits) and *Mesocricetus* (e.g., hamsters).

A "knock-out" animal is genetically manipulated to substantially reduce, or eliminate 30 endogenous capsaicin receptor function (and/or capsaicin receptor-related polypeptide function). Different approaches may be used to achieve the "knock-out". For example, a chromosomal deletion of all or part of the native capsaicin receptor homolog (or native capsaicin receptor-related polypeptide homolog) may be induced. Deletions of the non-coding regions, particularly the promoter region, 3' regulatory sequences, enhancers, or deletions of gene that activate expression of the capsaicin receptor gene and/or the capsaicin receptor-related polypeptide gene. A functional knock-out may also 35 be achieved by the introduction of an anti-sense construct that blocks expression of the native gene(s) (for example, see Li and Cohen (1996) *Cell* 85:319-329).

Conditional knock-outs of capsaicin receptor gene function (and/or capsaicin receptor-related polypeptide gene function) are also included within the present invention. Conditional knock-outs are

transgenic animals that exhibit a defect in capsaicin receptor gene function (and/or capsaicin receptor-related polypeptide gene function) upon exposure of the animal to a substance that promotes target gene alteration, introduction of an enzyme that promotes recombination at the target gene site (e.g., Cre in the Cre-loxP system), or other method for directing the target gene alteration.

5 For example, a transgenic animal having a conditional knock-out of capsaicin receptor gene function can be produced using the Cre-loxP recombination system (see, e.g., Kilby et al. 1993 Trends Genet 9:413-421). Cre is an enzyme that excises the DNA between two recognition sequences, termed loxP. This system can be used in a variety of ways to create conditional knock-outs of capsaicin receptor. For example, two independent transgenic mice can be produced: one transgenic for an 10 capsaicin receptor sequence flanked by loxP sites and a second transgenic for Cre. The Cre transgene can be under the control of an inducible or developmentally regulated promoter (Gu et al. 1993 Cell 73:1155-1164; Gu et al. 1994 Science 265:103-106), or under control of a tissue-specific or cell type-specific promoter (e.g., a neuron-specific promoter). The capsaicin receptor transgenic is then crossed with the Cre transgenic to produce progeny deficient for the capsaicin receptor gene only in those cells 15 that expressed Cre during development.

Transgenic animals may be made having an exogenous capsaicin receptor gene and/or exogenous capsaicin receptor-related polypeptide gene. The exogenous gene is usually either from a different species than the animal host, or is otherwise altered in its coding or non-coding sequence.

20 The introduced gene may be a wild-type gene, naturally occurring polymorphism, or a genetically manipulated sequence, for example those previously described with deletions, substitutions or insertions in the coding or non-coding regions. The introduced sequence may encode an capsaicin receptor polypeptide and/or capsaicin receptor-related polypeptide. Where the introduced gene is a coding sequence, it is usually operably linked to a promoter, which may be constitutive or inducible, and other regulatory sequences required for expression in the host animal.

25 Specific constructs of interest include, but are not limited to, anti-sense polynucleotides encoding capsaicin receptor or capsaicin receptor-related polypeptide, or a ribozyme based on a capsaicin receptor or capsaicin receptor-related polypeptide sequence, which will block capsaicin receptor expression or capsaicin receptor-related polypeptide expression, respectively. Such anti-sense polynucleotides or ribozymes will also block expression of dominant negative mutations and 30 over-expression of the corresponding gene. Also of interest is the expression of constructs encoding capsaicin receptor or capsaicin receptor-related polypeptides in a host where the capsaicin receptor and/or capsaicin receptor-related polypeptide encoded by the construct is derived from a different species than the species of the host in which it is expressed (e.g., expression of human capsaicin receptor in a transgenic mouse). A detectable marker, such as *lac Z* may be introduced into the 35 capsaicin receptor or capsaicin receptor-related polypeptide locus, where upregulation of expression of the corresponding gene will result in an easily detected change in phenotype. Constructs utilizing a promoter region of the capsaicin receptor gene or capsaicin receptor-related polypeptide gene in combination with a reporter gene are also of interest. Constructs having a sequence encoding a

truncated or altered (e.g., mutated) capsaicin receptor or capsaicin receptor-related polypeptide are also of interest.

The modified cells or animals are useful in the study of function and regulation of capsaicin receptor and capsaicin receptor-related polypeptide. Such modified cells or animals are also useful in, 5 for example, the study of the function of capsaicin receptor and capsaicin receptor-related polypeptides, as well as the study of the development of nociceptive neurons. Animals may also be used in functional studies, drug screening, etc., e.g. to determine the effect of a candidate drug on capsaicin receptor function or on symptoms associated with disease or conditions associated with capsaicin receptor function (e.g., capsaicin receptor defects or other altered capsaicin receptor activity). By providing 10 expression of capsaicin receptor polypeptide and/or capsaicin receptor-related polypeptide in cells in which it is otherwise not normally produced (e.g., ectopic expression), one can induce changes in cell behavior.

DNA constructs for homologous recombination will comprise at least a portion of the capsaicin receptor gene (or capsaicin receptor-related polypeptide gene) with the desired genetic modification, 15 and will include regions of homology to the target locus. DNA constructs for random integration need not include regions of homology to mediate recombination. Conveniently, markers for positive and negative selection are included. Methods for generating cells having targeted gene modifications through homologous recombination are known in the art. For various techniques for transfecting mammalian cells, see Keown et al. 1990 Methods in Enzymology 185:527-537.

20 For embryonic stem (ES) cells, an ES cell line may be employed, or embryonic cells may be obtained freshly from a host, e.g. mouse, rat, guinea pig, etc. Such cells are grown on an appropriate fibroblast-feeder layer or grown in the presence of appropriate growth factors, such as leukemia inhibiting factor (LIF). When ES cells have been transformed, they may be used to produce transgenic animals. After transformation, the cells are plated onto a feeder layer in an appropriate medium. Cells 25 containing the construct may be detected by employing a selective medium. After sufficient time for colonies to grow, they are picked and analyzed for the occurrence of homologous recombination or integration of the construct. Those colonies that are positive may then be used for embryo manipulation and blastocyst injection. Blastocysts are obtained from 4 to 6 week old superovulated females. The ES cells are trypsinized, and the modified cells are injected into the blastocoel of the blastocyst. After 30 injection, the blastocysts are returned to each uterine horn of pseudopregnant females. Females are then allowed to go to term and the resulting litters screened for mutant cells having the construct. By providing for a different phenotype of the blastocyst and the ES cells, chimeric progeny can be readily detected.

The chimeric animals are screened for the presence of the modified gene. Chimeric animals 35 having the modification (normally chimeric males) are mated with wildtype animals to produce heterozygotes, and the heterozygotes mated to produce homozygotes. If the gene alterations cause lethality at some point in development, tissues or organs can be maintained as allogeneic or congenic grafts or transplants, or in in vitro culture.

Investigation of genetic function may utilize non-mammalian models, particularly using those organisms that are biologically and genetically well-characterized, such as *C. elegans*, *D. melanogaster* and *S. cerevisiae*. For example, transposon (Tc1) insertions in the nematode homolog of a capsaicin receptor gene or a promoter region of a capsaicin receptor gene may be made. The capsaicin receptor 5 gene sequences may be used to knock-out or to complement defined genetic lesions in order to determine the physiological and biochemical pathways involved in function of neuronal cells. It is well known that human genes can complement mutations in lower eukaryotic models.

Biosensor Membranes Having Capsaicin Receptor Polypeptides

10 Due to the responsiveness of capsaicin receptor polypeptides to heat, capsaicin receptor polypeptides can be used in a biosensor for detection of changes in temperature. The biosensor utilizes electrochemical measurement of an ion current across a lipid membrane (or other medium) having a capsaicin receptor polypeptide incorporated therein. Upon stimulation of the capsaicin receptor polypeptide by heat, the capsaicin receptor polypeptide facilitates movement of ions (e.g., calcium) 15 across the membrane, which is then detected as a change in current across the lipid bilayer. The temperature and/or change in temperature can be correlated with the relative increase in conductance across the bilayer due to capsaicin receptor polypeptide activation.

It is well known that amphiphilic molecules can be caused to aggregate in solution to form two or three dimensional ordered arrays such as monolayers, micelles, black lipid membranes, and vesicles 20 or liposomes, which vesicles may have a single compartment or may be of the multilamellar type having a plurality of compartments. The membrane may contain any suitable combination of lipids, long-chain (C12-C24) organic compounds, as well as plastic materials or like polymers for physical reinforcement. Methods and compositions for manufacture of lipid bilayers incorporating a protein of interest, as well 25 as methods and compositions for manufacture of the electrical and mechanical components of biosensors are well known in the art (see, e.g., USPN 5,328,847 (thin membrane sensor with biochemical switch); USPN 5,443,955 (receptor membranes and ionophore gating); USPN 5,234,566 (sensitivity and selectivity of ion channel biosensor membranes); USPN 5,074,977 (digital biosensors and method of using same); and USPN 5,156,810 (biosensors employing electrical, optical, and mechanical signals), each of which are hereby incorporated by reference for manufacture and use of 30 biosensors incorporating a receptor of interest (i.e., capsaicin receptor).

Biosensors according to the present invention comprise at least one lipid membrane, where the membrane includes at least one capsaicin receptor polypeptide. Because capsaicin receptor polypeptides can function when contacted with ligand (e.g., capsaicin) or other effector that mediates capsaicin receptor activity (e.g., heat), the orientation of capsaicin receptor in the membrane is not substantially important for the function of the biosensor.

Conventional microelectronic configurations will serve adequately to supply power for the sensor, provide a constant direct current voltage across the bilayer prior to heat detection, and measure the ion current surge following capsaicin receptor activation elicited by a change in temperature. It may

be additionally desirable to incorporate into the detection electronics a provision for membrane integrity determination, based on the electrical noise accompanying a triggered current signal.

In general, heat is detected using the biosensor of the invention by detecting a change in conductance across the capsaicin receptor polypeptide-containing bilayer. For example, the capsaicin receptor polypeptide lipid bilayer is provided so that a first face of the lipid bilayer (the "heat detection face") is in contact with an buffer solution of neutral pH and containing a selected cation that is capable of transport by the capsaicin receptor (e.g., any cation such as calcium or magnesium, preferably sodium), while a second face of the capsaicin receptor polypeptide lipid bilayer is in contact with a neutral pH buffer having a concentration of the selected cation that is significantly less than the concentration of selected cation in the buffer bathing the heat detection face of the bilayer. Upon exposure of the bilayer's heat detection face to a change in temperature, heat facilitates capsaicin receptor function to provide for transport of the selected cation across the bilayer, resulting in a change in conductance across the bilayer. The change in conductance is then correlated with a change in temperature.

15

The examples below are provided to illustrate the subject invention and are not included for the purpose of limiting the invention.

EXAMPLES

20 Example 1: Expression Cloning of Rat Capsaicin Receptor-Encoding DNA

While electrophysiological assays in *Xenopus* oocytes have been employed to obtain cDNAs encoding a variety of cell surface receptors and ion channels (Brake et al. 1995 *Nature* 371:519-523), this approach proved unsuccessful in identifying a capsaicin receptor clone. A mammalian cell expression cloning strategy based on the ability of capsaicin to trigger an influx of calcium ions into 25 sensory neurons was developed. First, a rodent dorsal root ganglion plasmid cDNA library was constructed in pcDNA3 (Invitrogen) essentially as described (Brake et al., *supra*). A mixture of polyadenylated RNA from newborn (P1) rat and adult mouse dorsal root ganglia was used to generate first-strand cDNA using an oligo (dT) primer containing a Not1 restriction site. Following second strand synthesis and attachment of BstX1 adaptors, the cDNA was digested with Not1. cDNA and BstX1/Not1- 30 linearized pcDNA3 were each purified on potassium acetate gradients, ligated together, and transformed in DH5 α bacteria by electroporation. The resulting 2.4×10^6 independent bacterial clones were divided into 144 pools and stored at -80°C.

HEK 293 (human embryonal kidney) cells constitutively expressing the SV40 large T antigen were maintained in Medium A (DMEM supplemented with 10% fetal bovine serum (Hyclone), penicillin, 35 streptomycin, and L-glutamine) at 37°C, 5% CO₂. Except where indicated, transient transfections were carried out with nearly-confluent cells that were replated at 3.2×10^5 /35mm tissue culture dish. After 24hrs, the medium was replaced with 1ml Medium B (DMEM supplemented with 10% dialyzed fetal calf serum, penicillin, streptomycin, and L-glutamine). After 2 hrs at 37°C, cells were transfected with 12

μg plasmid DNA using a calcium phosphate precipitation kit (Specialty Media). The following day, cells were rinsed once with phosphate buffered saline (PBS) containing 1mM EDTA, washed from the plates, collected by centrifugation (200 x g, 5min, 22°C), resuspended in Medium B, and re-plated onto polyornithine-coated coverslips. Under these conditions, each cell acquired plasmids encoding 5 approximately 200 different cDNAs.

Between 6 and 24 hours later, cells were loaded with fura2 (30 min at 37°C) in CIB buffer(mM: 130 NaCl, 3 KCl, 2.5 CaCl₂, 0.6 MgCl₂, 1.2 NaHCO₃, 10 Glucose, 10 Hepes, pH 7.45) containing 10 μM fura-2 acetoxyethyl ester and 0.02% pluronic acid (Molecular Probes), then rinsed twice with CIB. Ratiometric calcium imaging was performed using a Nikon Diaphot fluorescence microscope equipped 10 with a variable filter wheel (Sutter Instruments) and an intensified CCD camera (Hamamatsu). Dual images (at 340 nm and 380 nm excitation, 510 nm emission) were collected and pseudocolor ratiometric images monitored during the experiment (Metafluor imaging software, Universal Imaging). Cells were initially imaged in 200 ml CIB, after which 200 ml CIB containing capsaicin at twice the desired concentration was added. Following stimuli, cells were observed for 60-120 s. For each library pool, 15 one microscopic field (300-500 cells) was assayed in each of eight wells.

While cells transfected with most of the assayed pools or with pcDNA3 alone exhibited no capsaicin responsiveness, 1% to 5% of the cells transfected with one of the cDNA library pools exhibited a profound increase in cytoplasmic calcium concentrations upon capsaicin treatment. cDNA from this pool was further subdivided into smaller pools, and those subpools retransfected into HEK293 cells. 20 In cell populations transfected with some of these subpools, an even larger fraction of cells responded to capsaicin, indicating that a capsaicin receptor-encoding cDNA had been enriched within the population. The process of pool subdivision and reassay was continued until a single plasmid was isolated that conferred capsaicin-responsiveness upon greater than 70% of the transfected cells. The clone that conferred capsaicin-responsiveness contained a 3 kb cDNA insert.

25

Example 2: Sequencing and Characterization of Capsaicin Receptor-Encoding cDNA

The 3 kb cDNA insert was sequenced using an automated sequencer (ABI). Homology searches were performed against the nonredundant Genbank database and against an EST database (dbest) using blastn, blastx, and tblastx search programs. Hydrophilicity was calculated using the 30 Hopp-Woods algorithm and a window size of ten 47. The insert was determined to be of rat origin by sequencing an independent cDNA isolated from a rat DRG library and a PCR product derived from mouse DRG cDNA. The sequence of the isolated rat capsaicin receptor-encoding polynucleotide (SEQ ID NO:1) and its corresponding amino acid sequence (SEQ ID NO:2) are shown in Figure 1. Because a vanilloid moiety constitutes an essential chemical component of capsaicin and resiniferatoxin 35 structures, the proposed site of action of these compounds is more generally referred to as the vanilloid receptor (Szallasi 1994 Gen. Pharmac. 25:223-243). Accordingly, the newly cloned cDNA was termed VR1, for vanilloid receptor subtype 1. The term "capsaicin receptor" as used herein encompasses VR1, but is not limited to VR1.

The VR1-encoding cDNA contains a 2514-nucleotide open reading frame encoding a protein of 838 amino acids with a predicted molecular mass of 95 kD (Figs. 1 and 2A). Hydrophilicity analysis suggests that VR1 is a polytopic protein containing 6 transmembrane domains (noted as "TM" and shaded boxes in Fig. 1 and predicted to be mostly β -sheet (see Fig. 1B)) with an additional short 5 hydrophobic stretch between transmembrane regions 5 and 6 (light shaded region). The amino-terminal hydrophilic segment (432 aa) contains a relatively proline-rich region followed by 3 ankyrin repeat domains (open boxes). The carboxyl-terminus (154 aa) contains no recognizable motifs.

A homology search of protein databases revealed significant similarities between VR1 and members of the family of putative store-operated calcium channels (SOCs) whose prototypical members 10 include the drosophila retinal proteins TRP and TRPL 32, 33 (Fig. 1C). Members of this family have been proposed to mediate the entry of extracellular calcium into cells in response to the depletion of intracellular calcium stores 34. These proteins resemble VR1 with respect to their predicted topological organization and the presence of multiple amino-terminal ankyrin repeats 33. There is also striking 15 amino acid sequence similarity between VR1 and SOCs within and adjacent to the sixth transmembrane region, including the short hydrophobic region between transmembrane domains 5 and 6 that may contribute to the ion permeation path 33. Outside these regions, VR1 shares little sequence similarity with SOCs, suggesting that VR1 is a distant relative of this family of channel proteins. Given the high permeability of VR1 to calcium ions, we nonetheless considered the possibility that it might function as a SOC.

20 An expressed sequence tag (EST) database homology search revealed several human clones bearing a high degree of similarity to VR1 at both the nucleotide and predicted amino acid levels (Fig. 1C). Three of these partial cDNAs, independently isolated from different sources, encode sequences in the vicinity of the predicted VR1 pore-loop and sixth transmembrane domains. As shown in Figure 2C, the similarity of one of these clones (hVR, Genbank accession T12251) to the corresponding region 25 of VR1 is extremely high (68% amino acid identity and 84% similarity within the region shown), suggesting that it is likely to be the human VR1 orthologue or a closely related subtype. Human EST clones corresponding to other domains of VR1 show comparable degrees of similarity (not shown) and could represent fragments of the same human transcript.

30 **Example 3: VR1 Does Not Function as a Store-Operated Calcium Channel (SOC)**

The amino acid sequence similarities between VR1 and SOCs suggested that the capsaicin receptor might function as an SOC. To test this, calcium-dependent inward currents were examined in VR1-expressing, intracellular calcium-depleted oocytes according to methods well known in the art.

Briefly, cRNA transcripts were synthesized from Not1- linearized VR1 cDNA templates using 35 T7 RNA polymerase 17. Defolliculated *Xenopus laevis* oocytes were injected with 0.5 - 5ng VR1 cRNA. Four to seven days after injection, two electrode voltage clamp recording was performed ($E_{hold} = -60$ mV for IC_{50} curve and thermal stimulation experiments, and -40 mV for all other experiments) using a Geneclamp 500 amplifier (Axon Instruments) and a MacLab A/D converter (Maclab). The recording

chamber was perfused at a rate of 2 ml/min with frog ringers solution containing (mM) 90 NaCl; 1.0 KCl, 2.4 NaHCO₃, 0.1 BaCl₂, 1.0 MgCl₂, and 10 HEPES, pH 7.6. at room temperature. Prior to performing the store-operated current assays, oocytes were incubated for 1-2 hrs in calcium-free, barium-free frog ringer's solution containing 1 mM EGTA and 1 μ M Thapsigargin. During voltage clamp recording, these 5 oocytes were intermittently exposed to frog ringer's solution containing 2 mM Ca²⁺ and no EGTA to detect calcium-dependent currents (15 second pulses at 2 minute intervals) (Petersen et al. 1995 Biochem J. 311:41-44).

In water-injected control oocytes, a clear depletion-induced current was seen, as previously described (Petersen et al., *supra*). In VR1-expressing oocytes, no quantitative or qualitative differences 10 were observed in this response (not shown). Moreover, application of SKF 96365 (20 μ M), an inhibitor of depletion-stimulated calcium entry (Merritt et al. 1990 Biochem J. 271:515-522), had no effect on capsaicin-evoked currents in VR1-expressing oocytes. Thus, VR1 does not appear to be a functional SOC under these circumstances.

15 **Example 4: Sensory Neuron-Specific Expression of Capsaicin Receptor**

The distribution of VR1 transcripts in neuronal and non-neuronal rat tissues was assessed by both Northern blot and in situ hybridization analyses. Adult Sprague-Dawley rats were euthanized by asphyxiation in CO₂ and tissues freshly dissected. Poly A+ RNA was purified either by lysis in guanidinium isothiocyanate followed by purification on oligo-dT cellulose or with the FastTrack kit 20 (Invitrogen). Approximately 2 μ g of each sample was electrophoresed through a 0.8% agarose-formaldehyde gel, transferred to a nylon membrane (Hybond N, Amersham), and hybridized with a ³²P-labeled probe representing the entire VR 1 cDNA. Blots were washed at high stringency and autoradiographed. After probing with capsaicin receptor cDNA, the same filters were reprobed with a radiolabeled cyclophilin cDNA fragment as a control (e.g., to correct for relative RNA loading between 25 samples).

For in situ hybridization histochemistry, adult female Sprague-Dawley rats were anesthetized and perfused with 4% paraformaldehyde in PBS. Dorsal root ganglia, trigeminal ganglia and spinal cord were dissected, frozen in liquid N₂, embedded in OCT mounting medium, and sectioned on a cryostat. Sections (15 micron) were processed and probed at 55 °C overnight with a digoxigenin-labeled cRNA 30 generated by in vitro transcription of a 1kb fragment of the VR1 cDNA (nt 1513-2482) using the Genius kit (Boehringer Mannheim). Sections were developed with alkaline phosphatase-conjugated anti-digoxigenin Fab fragments according to the manufacturer's instructions.

Both Northern blot analysis and in situ hybridization histochemistry indicated that VR1 transcripts are expressed selectively within dorsal root and trigeminal ganglia. An mRNA species of 35 approximately 4 kb was prominently expressed in trigeminal and dorsal root sensory ganglia, both of which have been shown to contain capsaicin-sensitive neurons. This transcript was absent from all other tissues examined, including spinal cord and brain. A much smaller RNA species (approx. 1.5 kb)

was detected in the kidney, but it is unclear whether this transcript could encode a functional VR1 protein.

In situ hybridization to assess the cellular pattern of VR1 expression within sensory ganglia showed that VR1 was expressed predominately within a subset of neurons with small diameters within 5 both dorsal root and trigeminal ganglia. This is in keeping with the observation that most capsaicin-sensitive neurons have relatively small- to medium-sized cell bodies (Holzer 1991 *Pharmacol. Rev.* 43:143-201; Jansco et al. 1977 *Nature* 270:741-743). In contrast to the predominant expression of VR1 transcripts in neurons of the dorsal root ganglion, no visible signal was observed in the adjacent spinal cord dorsal horn. While binding sites for radiolabeled resiniferatoxin have been detected in the dorsal 10 horn, these sites are believed to reside on presynaptic terminal that project from primary nociceptors located within adjacent dorsal root ganglia (Holzer 1991, *supra*). The results here support this interpretation.

Example 5: Assessment of VR1 Pharmacology in *Xenopus* Oocytes

15 To compare the pharmacological properties of the cloned capsaicin receptor to those of native vanilloid sites in sensory ganglia, VR1 was expressed in oocyte and used in whole-cell voltage clamp analysis to quantitatively examine its electrophysiological response to a variety of vanilloid agonists (capsaicin, resiniferatoxin) and antagonists (capsazepine). VR1 was expressed in *Xenopus* oocytes as described above (Example 3), except that CaCl_2 (2 mM) was used in place of BaCl_2 when generating 20 the capsazepine inhibition curve. The agonists capsaicin and resiniferatoxin were applied sequentially to the same *Xenopus* oocyte expressing VR1. Membrane currents were recorded in the whole cell voltage clamp configuration ($V_{\text{hold}} = -40\text{mV}$).

The results of the capsaicin and resiniferatoxin studies are shown in Figs. 10A-10B. Bars 25 denote duration of agonist application. At negative holding potentials, exposure to capsaicin or resiniferatoxin produced dose-dependent inward current responses in VR1 expressing oocytes, but not in water-injected control cells. As observed in sensory neurons (Winter et al. 1990 *Brain Res.* 520:131-140; Liu et al. 1994 *Proc. Natl. Acad. Sci. USA* 91:738-741), capsaicin-evoked current responses returned rapidly to baseline following agonist removal, whereas resiniferatoxin responses often failed to recover, even after a prolonged washout period. Half-maximal effective concentrations for these 30 agonists were within an order of magnitude of those reported for native vanilloid receptors (Oh et al., *supra*; Bevan et al. 1992 *Br. J. Pharmacol.* 107:544-552), with resiniferatoxin being approximately 20-fold more potent than capsaicin ($\text{EC}_{50} = 39.1\text{ nM}$ and 711.9 nM , respectively). Hill coefficients derived from these analyses (1.95 and 2.08, respectively) suggest that full activation of the receptor involves the binding of more than one agonist molecule, again consistent with previously described 35 properties of native vanilloid receptors (Oh et al., *supra*; Szallasi 1994 *Gen. Pharmac.* 25:223-243).

As shown in Figs. 11A and 11B, capsaicin-evoked responses in VR1 expressing oocytes were blocked by the competitive vanilloid receptor antagonist capsazepine at concentrations ($\text{IC}_{50} = 283.5\text{ nM}$) that inhibit native receptors (Figs. 10A-10B). The current tracing shows that the block of capsaicin

activity (cap; 0.6 μ M) by capzasepine (cpz; 10 μ M) is reversible. Another pharmacological signature of vanilloid receptors is their sensitivity to the non-competitive antagonist ruthenium red (RR; 10 μ M), which also blocked capsaicin-evoked responses (cap; 0.6 μ M) in a reversible manner (Figs. 11A). Responses to resiniferatoxin (50 nM) were also reversibly antagonized by capsazepine (5 μ M) or 5 ruthenium red (10 μ M) (not shown).

Example 6: Patch clamp analysis of recombinant capsaicin receptors expressed in HEK293 embryonal kidney cells

The recombinant capsaicin receptor cloned in Example 1 was further characterized in studies 10 using patch clamp analysis in capsaicin receptor-expressing HEK293 cells. HEK293 cells transfected with a control vector (pcDNA3 without a capsaicin receptor-encoding sequence). Patch-clamp recordings were carried out with transiently transfected HEK293 cells at 22°C. Standard bath solution for whole-cell recordings contained (mM) 140 NaCl, 5 KCl, 2 MgCl₂, 2 CaCl₂, 10 HEPES, 10 glucose, pH 7.4 (adjusted with NaOH). In calcium-free bath solution, CaCl₂ was removed and 5 mM EGTA was 15 added.

For monovalent cation substitution experiments, after the whole-cell configuration was obtained in control bath solution, the bath solution was changed to (mM): 140 NaCl (or KCl or CsCl), 10 glucose, and 10 HEPES (adjusted to pH 7.4 with NaOH, KOH or CsOH, respectively) and the reversal potential measured using voltage-ramps. For divalent cation permeability experiments, the bath solution was 20 changed to (mM) 110 MgCl₂ (or CaCl₂), 2 Mg(OH)₂ (or Ca(OH)₂), 10 glucose, 10 HEPES, pH 7.4 (adjusted with HCl).

Bath solution for outside-out patch recordings and pipette solution for inside-out patch recordings contained (mM) 140 NaCl, 10 HEPES, pH 7.4 (adjusted with NaOH). Bath solution for inside-out patch recordings and pipette solutions for outside-out patch recordings and ion substitution 25 experiments contained: (mM) 140 NaCl, 10 HEPES, 5 EGTA, pH 7.4 (adjusted with NaOH). Pipette solution for whole-cell recordings contained (mM) 140 CsCl (or 130 CsAspartate and 10 NaCl), 5 EGTA, 10 HEPES, pH 7.4 (adjusted with CsOH). Liquid junction potentials were measured directly in separate experiments; they did not exceed 3 mV with solutions used and no correction for this offset was made.

30 Whole-cell recording data were sampled at 20 kHz and filtered at 5 kHz for analysis (Axopatch 200 amplifier with pCLAMP software, Axon Instruments). Single-channel recording data were sampled at 10 kHz and filtered at 1 kHz. Permeability ratios for monovalent cations to Na (P_x/P_{Na}) were calculated as follows: $P_x/P_{Na} = \exp(\Delta V_{rev}F/RT)$, where V_{rev} is the reversal potential, F is Faraday's constant, R is the universal gas constant, and T is absolute temperature. For measurements of divalent 35 permeability, P_y/P_{Na} was calculated as follows: $P_y/P_{Na} = [Na^+]/\exp(\Delta V_{rev}F/RT)(1+\exp(\Delta V_{rev}F/RT))/4[Y^{2+}]_o$. Ion activity coefficients of 0.75 (sodium) and 0.25 (calcium or magnesium) were used as correction factors.

Figure 3 show the results of whole cell voltage clamp analysis of capsaicin receptor-expressing HEK293 cells at -60mV using a CsAspartate-filled pipet. These data show an inward cation-specific current which is present only during capsaicin treatment (the time period during which capsaicin was present (1 μ M) is indicated by the bar above the plot), and which developed with a short latency upon 5 bath application of capsaicin. No such currents were observed on control, mock-transfected cells. Figure 4 shows the voltage steps (400ms) from -100 mV to +40mV (vertical lines in Figure 3) on an expanded time scale. The currents in the absence of capsaicin (a) were subtracted from the currents obtained in the presence of capsaicin (b). This analysis of the data revealed a time-independent, 10 receptor-dependent current. In calcium-free medium, the capsaicin-evoked current was also time-independent both at a constant holding potential of -60 mV (Fig. 3) and during voltage steps from -100 to +40 mV (in 20mV increments, Fig. 4). This property enabled characterization of capsaicin-mediated currents under steady-states response conditions in subsequent experiments. Current- voltage relations derived from these data show that such responses exhibit prominent outward rectification 15 resembling that observed in cultured dorsal root ganglion neurons (Fig. 4; Oh et al., *supra*). Because the bath solution used in these experiments consisted mainly of sodium chloride, whereas the patch pipet was filled with cesium aspartate, the observed reversal potential close to 0 mV ($E_{rev} = 0.5 \pm 0.9$ mV; n=13) indicates that the capsaicin-mediated response involves the opening of a cation-selective 20 channel.

In sensory neurons, vanilloid-evoked currents are carried by a mixture of mono- and divalent 25 cations (Bevan et al. 1990 Trends Pharmacol. Sci. 11:330-333; Oh et al., *supra*; Wood et al. 1988 J. Neuroscience 8:3208-3220). This phenomena was examined in VR1-expressing mammalian cells through a series of ion substitution experiments to examine the relative contributions of various cations to capsaicin-evoked currents in VR1-expressing cells. Current-voltage relations established for cells bathed in solutions of differing cationic compositions (Fig. 5; Na⁺ (labeled a), K⁺ (labeled b), Cs⁺ (labeled c), Mg⁺⁺ (labeled d), or Ca⁺⁺ (labeled e) revealed that VR1 does not discriminate among monovalent 30 cations, but exhibits a notable preference for divalent cations. Replacement of extracellular NaCl (140 mM) with equimolar KCl or CsCl did not significantly shift reversal potential ($E_{rev} = -0.7 \pm 1.2$ mV, n= 8; -1.5 mV, n=9; -4.3 \pm 0.9 mV, n=8, respectively. $P_K/P_{Na} = 0.94$; $P_{Cs}/P_{Na} = 0.85$). Replacement of extracellular NaCl with isotonic (112 mM) MgCl₂ or CaCl₂ shifted E_{rev} to 14.4 \pm 1.3 mV (n=3) or 24.3 \pm 35 2.3 mV (n=7), respectively. As summarized in Fig. 5, the data thus revealed that the capsaicin receptor-expressing cell membranes had the following relative cation permeabilities for the capsaicin-activated current: Ca⁺⁺ > Mg⁺⁺ >> Na⁺ \approx K⁺ \approx Cs⁺. The very high relative permeability of VR1 to calcium ions ($P_{Ca}/P_{Na} = 9.60$; $P_{Mg}/P_{Na} = 4.99$) exceeds that observed for most non-selective cation channels and is comparable to values reported for NMDA-type glutamate receptors ($P_{Ca}/P_{Na} = 10.6$) (Mayer et al. 1987 J. Physiol. 394:501-527), which are noted for this property. With all bath solutions examined, an outwardly rectifying current-voltage relation was observed, although this feature was somewhat less prominent in MgCl₂- or CaCl₂-containing bath solutions.

In cultured sensory neurons, electrophysiological analyses of vanilloid-evoked responses have shown them to be kinetically complex and to desensitize with continuous vanilloid exposure (Liu et al., *supra*; Yeats et al. 1992 *J. Physiol.* 446:390P). This electrophysiological desensitization (which might underlie aspects of physiological desensitization produced by vanilloids *in vivo*) appears to depend, in part, upon the presence of extracellular calcium (Yeats et al., *supra*; Holzer 1991 *Pharmacol. Rev.* 43:143-201). To test the calcium dependency of VR1-expressing cells ability to respond to capsaicin, whole-cell current responses were tested in both calcium-containing standard bath solution and in calcium-free solution (Fig. 6A-F). Capsaicin (1 μ M) was applied every 5 min; CsCl was used as pipette solution. The ratios of current size at the end of the third application to the peak of the first application were $95.3 \pm 2.6\%$ ($n = 3$) in calcium-free solution, and $13.0 \pm 4.3\%$ ($n=5$) in calcium-containing solution (T test; $p < 0.00001$). Indeed, in the absence of extracellular calcium, capsaicin-evoked responses in VR1-transfected cells showed little or no desensitization during prolonged agonist application or with successive agonist challenges ($4.7 \pm 2.3\%$ decrease between first and third applications, $n=3$). In contrast, responses evoked in calcium-containing bath solution consisted of at least two distinct components: one desensitizing ($87 \pm 4.3\%$ decrease between first and third applications, $n=5$); and one relatively non-desensitizing. Thus, desensitization and multiphasic kinetics of vanilloid-evoked responses can be reproduced outside of a neuronal context and distinguished by their dependence on ambient calcium levels.

The behavior of the VR1 response was also examined in membrane patches excised from transfected cells. Inside-out (I/O) or outside-out (O/O) patches were excised from VR1-transfected cells and analyzed in symmetrical 140 mM NaCl at the indicated holding potentials with capsaicin (1 μ M) in the bath solution. Dashed lines in the data represented in Fig. 7 indicate closed channel state. In other patches, multiple simultaneous channel openings were observed. The large and well resolved currents of unitary amplitude observed only in the presence of capsaicin (Fig. 7) indicate the existence of capsaicin-gated ion channels within these patches, whose activation does not depend upon soluble cytoplasmic components. The current voltage curve of mean single channel amplitudes (\pm s.e.m.; Fig. 8), which was calculated from data shown in Fig. 7, also exhibits pronounced outward rectification. The current-voltage relation at the single-channel level was essentially identical to that established in whole-cell configuration, owing to its outward rectification and reversal potential near 0 mV under similar ionic conditions. Unitary conductances of 76.7 pS at positive potentials and 35.4 pS at negative potentials were observed with sodium as the sole charge carrier. These single channel properties mirror those previously described for native vanilloid receptors (Oh et al., *supra*; Forbes et al. 1988 *Neurosci. Lett. Suppl.* 32:S3).

It has been suggested that the site of vanilloid action may not be confined to the extracellular side of the plasma membrane, reflecting the lipophilic nature of these compounds (James et al. in *Capsaicin in the Study of Pain* (ed. Wood) Pgs. 83-104 (Academic Press, London, 1993). Interestingly, capsaicin was able to produce identical responses when added to either side of a patch excised from a VR1-expressing cell (Fig. 7), consistent with the notion that vanilloids can permeate or cross the lipid

bilayer to mediate their effects. A less likely, but formally consistent explanation is that vanilloid receptors have functionally equivalent capsaicin binding sites on both sides of the plasma membrane.

These data show that the cloned capsaicin receptor behaves in patch clamp analysis in a manner very similar to that reported for wildtype capsaicin receptor.

5

Example 7: Use of Recombinant Capsaicin Receptor to Quantitate Vanilloid Concentrations

As has been recognized for years, the relative pungencies of pepper varieties span an enormously wide range, reflecting, in part, differences in vanilloid content. To-date, methods for rating peppers with respect to their relative "hotness" have relied on subjective psychophysical assays (in which values are reported in Scoville units) (Scoville 1912 J. Am. Pharm. Assoc. 1:453-454) or on biochemical determination of capsaicin content (Woodbury 1980 J. Assoc. Off. Anal. Chem. 63:556-558). To further explore whether the electrophysiological response of the cloned vanilloid receptor to pepper extracts was in proportion to ability of these peppers to evoke pain.

Several different types of hot peppers (15 g; Thai green, poblano verde, habanero, and wax) were minced and extracted overnight at room temperature with 50 ml absolute ethanol. Soluble extracts were concentrated 15-fold by vacuum desiccation, then diluted 1000-fold in frog ringer's solution for electrophysiological assay. Equivalent fractions (normalized to pepper weight) were tested for their ability to activate the recombinant capsaicin receptor expressed in *Xenopus* oocytes. Capsaicin receptor activation was assessed using a two-electrode voltage-clamp assay to quantitatively measure currents elicited by each pepper extract. Responses were normalized to the response obtained with pure capsaicin (10 μ M set at 100). The data are shown in Fig. 11 (each value represents an average of four independent determinations, each from separate oocytes; 30 sec application). The relative response of the cloned receptor to the pepper samples and the capsaicin control are shown in the histogram with representative current traces shown to the right of each bar in the histogram. Extracts evoked no response in water-injected cells.

The relative responses of capsaicin receptor to the pepper extracts correlates with the relative hotness of each pepper as determined by conventional analyses and Scoville heat unit assignments. Moreover, the differential "hotness" of these pepper variants, as determined by subjective psychophysical ratings (Berkeley et al. Peppers: A Cookbook pgs. 1-120 (Simon and Schuster, New York, 1992), correlated with their rank order potencies as activators of VR1.

Example 8: Capsaicin Induces Death of Cells Expressing VR1

Capsaicin is widely recognized as a neurotoxin that selectively destroys primary afferent nociceptors *in vivo* and *in vitro* (Jansco et al. 1977 Nature 270:741-743; Wood et al. 1988 J. Neuroscience 8:3208-3220). In order to determine whether this selective toxicity solely is a reflection of the specificity of receptor expression, or whether it depends upon additional properties of sensory neurons or their milieu, the ability of capsaicin to kill non-neuronal cells expressing vanilloid receptors was examined *in vitro*. HEK293 cells were transiently transfected with either vector alone (pcDNA3),

vanilloid receptor cDNA diluted 1:50 in pcDNA3 (VR1 1:50) or vanilloid receptor cDNA alone (VR1). Fourteen hours later, culture medium was replaced with medium containing capsaicin (3 μ M, filled bars) or vehicle (ethanol 0.3%, open bars) (Fig. 12). After seven hours at 37°C, the percentage of dead cells was determined using ethidium homodimer staining. Data represent the mean \pm s.e.m. of triplicate determinations from a representative experiment. Asterisks indicate a significant difference from ethanol-treated cells (T-test, $P < 0.0001$). Similar results were obtained in three independent experiments.

As shown in Fig. 12, within several hours of continuous exposure to capsaicin, HEK293 cells transfected with VR1 exhibited rampant death, as determined morphologically and by the use of vital stains. In contrast, cells transfected with vector alone were not killed by this treatment. The cell death was characterized by prominent cytoplasmic swelling, coalescence of cytoplasmic contents, and eventual lysis. Thus, VR1 expression in a non-neuronal context can recapitulate the cytotoxicity observed in vanilloid-treated sensory neurons. Staining with Hoechst dye 33342 revealed no evidence of the nuclear fragmentation often associated with apoptotic cell death 28 (not shown). Together, these observations are consistent with necrotic cell death resulting from excessive ion influx, as has been proposed for vanilloid-induced death of nociceptors (Bevan et al. 1990 Trends Pharmacol. Sci. 11:330-333), glutamate-induced excitotoxicity (Choi 1994 Prog. Brain Res. 199:47-51), and neurodegeneration caused by constitutively activating mutations of various ion channels (Hong et al. 1994 Nature 367:470-473; Hess 1996 Neuron 16:1073-1076).

20

Example 9: Hydrogen ions potentiate the effect of capsaicin on VR1

A reduction in tissue pH resulting from infection, inflammation, or ischemia can produce pain in mammals. This effect has been attributed to the ability of protons to activate excitatory channels on the surface of nociceptive neurons. A subset of these responses have been reported to share properties in common with those elicited by vanilloids, including similar kinetics, ion selectivity, and antagonism by ruthenium red (Bevan et al. 1994 Trends Neurosci. 17:509-512). Moreover, subthreshold concentrations of hydrogen ions have been shown to potentiate the effects of low concentrations of capsaicin in sensory neurons (Petersen et al. 1993 Pain 54:37-42; Kress et al. 1996 Neurosci. Lett. 211:5-8). It has therefore been proposed that protons might act as endogenous activators or modulators of vanilloid receptors (Bevan et al. 1994 *supra*).

To address this possibility, the effects of hydrogen ions on the cloned vanilloid receptor were examined using the oocyte expression system. Capsaicin (0.3 μ M) was administered throughout the time period tested (spanned by the arrows in Fig. 13) ($V_{hold} = -40$ mV). The pH of the bath solution was changed during the experiment (as indicated by the horizontal bars in Fig. 13). VR1-expressing oocytes exhibited no responses to pH 6.3 bath solution without capsaicin; water-injected control oocytes exhibited no responses to either capsaicin or pH 6.3 bath solution (not shown). The current responses obtained from 9 independent VR1-expressing oocytes are summarized in Fig. 14. The grey portion of

each bar indicates peak current evoked by capsaicin at pH 7.6, while the black portion represents the additional current evoked by changing the pH to 6.3.

Abrupt reduction in bath solution pH (from 7.6 to 5.5) was not sufficient to activate VR1 in the absence of capsaicin (fewer than 10% of VR1-expressing oocytes treated in this way exhibited a large 5 inward current (not shown)), suggesting that hydrogen ions alone cannot efficiently activate this protein.

Next, the effect of both capsaicin and pH on VR1 activation was examined. VR1-expressing oocytes were treated with a submaximal concentration of capsaicin (500 nM) at pH 7.6 (Fig. 13). Once their current responses reached a relatively stable plateau, the oocytes were exposed to a solution containing the same concentration of capsaicin at pH 6.3. Under these conditions, the inward current 10 rapidly increased to a new plateau up to five-fold greater in magnitude than the first. Upon returning to pH 7.6, the oocyte response subsided to its initial plateau, and upon the removal of capsaicin it returned to baseline. This potentiation was seen only with sub-saturating concentrations of agonist, as reduced pH did not augment responses to 10 μ M capsaicin (not shown). These results suggest that while 15 hydrogen ions alone are not sufficient to activate VR1, they can markedly potentiate capsaicin-evoked responses.

Example 10: The vanilloid receptor is activated by noxious heat

The effects of elevated temperature on VR1 activity in calcium influx, conductance, and capsaicin and RR responsivity were examined.

20 **a) Effect of heat upon intracellular calcium**

The effects of heat upon VR1 activity in mediating calcium influx were examined using transfected HEK293 cells and the fluorescent calcium influx screening method described above. Cells were analyzed using microscopic fluorescent calcium imaging before and immediately after the addition of heated calcium imaging buffer (300 ml CIB at 65°C was applied to cells residing in 150 ml CIB at 25 22°C.) Under these conditions, cells were transiently exposed to a peak temperature of ~45°C.

While cells transfected with vector alone exhibited only a mild, diffuse change in cytoplasmic free calcium, a large proportion of cells expressing VR1 exhibited a pronounced elevation of calcium levels within seconds of heat treatment. These responses subsided within a few minutes and a subsequent challenge with capsaicin produced a characteristic calcium response, suggesting that the 30 response to heat is a specific signaling event and not a consequence of non-specific membrane perturbation or disruption to cell integrity.

b) Effect of heat upon conductance

Whole-cell patch-clamp analysis ($V_{hold} = -60$ mV) of VR1-transfected HEK293 cells was performed to examine whether specific heat-evoked membrane currents are associated with this 35 phenomenon. The temperature of the bath medium was raised from 22°C to 48°C (heat) and then restored to 22°C, after which capsaicin (0.5 μ M) was added to the bath. Ionic conditions were identical to those described for the data in Fig. 2. Voltage-ramps (-100 to +40 mV in 500 ms) were applied before, between, and during responses.

Exposure of these cells to a rapid increase in temperature (22°C to 50°C in 25 seconds, monitored with an in-bath thermistor) produced large inward currents (791 ± 235 pA at -60 mV; n=9) that were typically similar in amplitude to that evoked by a subsequent application of capsaicin at 500 nM (Fig. 15A). Both heat- and vanilloid-evoked responses showed outward rectification, suggesting that 5 they are mediated by the same entity (Fig. 15B). By comparison, thermally-evoked responses of control, vector-transfected cells were much smaller and exhibited no rectification (131 ± 23 nA, n=8). In addition, the heat response in VR1-transfected cells desensitized during stimulus application, whereas the small thermal response observed in control vector-transfected cells did not. These results suggest that VR1 is acting as a thermal transducer, either by itself or in conjunction with other cellular 10 components.

c) Heat activation of VR1 in oocytes

To determine whether VR1 could mediate similar responses to heat in a different cellular environment, heat activation of VR1 was tested in the oocyte system. Oocytes injected with either VR1 cRNA or water were subjected to two-electrode voltage-clamp ($V_{hold} = -60$ mV) while the temperature 15 of the perfusing buffer was raised from 22.7°C to the level indicated, then held constant for 60 sec. The magnitudes of the resulting inward currents are shown in Fig. 16 as the mean \pm s.e.m. (VR1, n = 8; water, n=6 independent cells). The asterisk indicates a significant difference from water-injected oocytes (T-test, P < 0.0005).

In control, water injected oocytes, acute elevation of perfusate temperature produced a small 20 inward current that increased linearly up to 50°C (Fig. 16). VR1 expressing oocytes exhibited similar responses at temperatures up to 40°C, but above this threshold, their responses were significantly larger than those of controls. Thus, even in this non-mammalian context, the VR1-mediated temperature response profile is remarkably consistent with that reported for thermal nociceptors (Fields, *supra*).

d) Inhibition of VR1 heat activation by ruthenium red

To further determine whether heat acts specifically through the capsaicin receptor, the ability of ruthenium red to inhibit the heat-mediated response was tested in VR1-expressing oocytes in the system described above. The current tracings shown in Fig. 17 were generated from representative VR1- or water-injected oocytes ($V_{hold} = -60$ mV) during successive applications of the indicated stimuli. 30

VR1-injected oocytes exhibited the following mean inward current responses \pm s.e.m. (n=5): capsaicin (1 μ M), 1221 ± 148 nA; heat (50 °C), 2009 ± 134 nA; heat plus ruthenium red (10 μ M), 243 ± 47 nA. Inhibition by ruthenium red was significant ($88 \pm 2\%$, n=5; Paired T-test, P < 0.0001). No diminution in current response was observed when successive heat pulses were administered in the 35 absence of ruthenium red. Water-injected oocytes showed no response to capsaicin and much smaller responses to heat (338 ± 101 nA, n=5). Ruthenium red inhibited these responses by only $21 \pm 26\%$ (n=5; Paired T-test, P < 0.1).

These data indicate that VR1 is directly involved in this thermal response; application of ruthenium red reduced significantly ($88 \pm 2\%$; n=5) the response of VR1-expressing oocytes to heat, while the smaller response seen in control cells was reduced by only $21 \pm 26\%$ (n=5) (Fig. 17). Taken together, these observations strongly support the hypothesis that VR1 is activated by noxious, but not 5 innocuous heat.

Example 11: Chromosomal localization and isolation of the mouse VR1 gene

The chromosomal localization of the mouse VR1 gene was determined using fluorescent in situ hybridization (FISH) according to methods well known in the art. Briefly, a bacterial artificial 10 chromosome containing a 90-100 kb insert of mouse genomic DNA encoding portions of the mouse VR1 gene was isolated by PCR analysis and Southern hybridization using rat VR1-derived probes. This insert was labeled with digoxigenin and applied to metaphase spreads of mouse chromosomes. Fluorescently tagged anti-digoxigenin antibodies were then used to visualize the position on the chromosomes to which the VR1 gene hybridized.

15 The VR1 gene mapped to the B3 band of mouse chromosome 11, approximately 49% of the way from the heterochromatic-euchromatic boundary to the telomere of chromosome 11. This region of the mouse chromosome is syntenic to human chromosome 17, particularly the regions 17p11-13, 17pter, and 17qter. It is therefore probable that the human VR1 gene is located within those analogous regions on the human chromosome.

20 The mouse VR1 gene was sequenced according to methods well known in the art. The nucleotide (SEQ ID NO:10) and amino acid (SEQ ID NO:11) sequences of mouse VR1 are provided in the Sequence Listing below. The rat and mouse VR1 amino acid sequences are more than 95% identical.

25 Example 12: Identification of capsaicin receptor-related polypeptide VRRP-1

A Genbank database search using VR1 revealed a number of human and mouse EST sequences similar VR1. Alignment of these EST sequences suggested that all of them, except one (see below) encode identical or very similar genes, suggesting that they represent fragments of the human and mouse versions of the VR1 gene. Over all regions analyzed, the predicted sequences of the 30 encoded human and mouse proteins were highly identical to one another, but only about 50% identical to the rat VR1. Because mouse VR1 protein is more similar to the rat VR1 protein than 50%, we concluded that these EST sequences must encode human and mouse versions of a related protein, which we have termed VRRP-1. VRRP-1 is an example of the capsaicin receptor-related polypeptides encompassed by the present invention.

35 Portions of the VRRP-1 genes from mouse brain, rat brain, and human CCRF-CEM cells were cloned using PCR primers (GAC CAG CAA GTA CCT CAC (SEQ ID NO:12) and C TCC CAT GCA GCC CAG TTT ACT TCC TCC ACC CTG AAG CAC CAG CGC TCA (SEQ ID NO:13))), which were based on the consensus of human and mouse EST sequences. A full-length rat VRRP-1 cDNA was isolated

from a rat brain cDNA library using the rat PCR product as a radiolabeled probe. The rat VRRP-1 cDNA (SEQ ID NO:3; amino acid sequence SEQ ID NO:4)) is approximately 49% identical to rat VR1 at the amino acid level (SEQ ID NOS:2 (rat VR1) and 4 (rat VRRP-1)) and 59% identical at the nucleotide level (SEQ ID NOS:1 (rat VR1) and 3 (rat VRRP-1)).

5 VRRP-1 does not appear to be activated by capsaicin or heat. Preliminary evidence suggests VRRP-1 may interact with VR1.

Example 13: Identification of human capsaicin receptor VR1

10 Comparison of VR1 with VRRP-1 and other sequences in the Genbank database suggest that VR1 and VRRP-1 are much more closely related to one another than to any other cloned sequences, with one exception. A single human EST sequence (accession number AA321554; SEQ ID NO:8) obtained from human CCRF-CEM lymphoid cells encodes an amino acid sequence (SEQ ID NO:9) that is at least 71% identical and at least 80% similar to the predicted extreme carboxy terminal domain of the rat VR1 (amino acid residues 774 to 838 of SEQ ID NO:2; see Region 2 of the schematic in Fig. 18).
15 Moreover, rat VR1 (SEQ ID NO:1) and the human EST AA321554 (SEQ ID NO:8) are 75% identical at the nucleotide level. In addition, EST AA321554 contains a stop codon in the same position as the stop codon in rat VR1. In contrast, although there is homology between a portion of EST AA321554 and the carboxy terminus of rat VRRP-1 (see Region 1 in Fig. 18), the rat VRRP-1 polypeptide is shorter than the rat VR1 polypeptide and the protein from which EST AA321554 appears to be derived.
20 Moreover, even with in Region 1, there is greater homology between rat VR1 and EST AA321554 than between either rat VR1 and rat VRRP-1 or than between rat VRRP-1 and EST AA321554. Therefore, the human EST sequence AA321554 represents the human version (ortholog) of rat VR1.

25 PCR primers based upon the human sequence were designed to amplify this fragment from cDNA isolated from CCRF-CEM cells or from human sensory ganglion cDNA. The resulting fragment is used as a probe to screen a human genomic DNA library to obtain a full-length human VR1 cDNA sequence from CCRF-CEM cell or human sensory ganglion cDNA. Using the resulting human VR1 genomic fragment, the chromosomal localization of the VR1 gene is confirmed by FISH. The function of the polypeptide encoded by the human VR1 gene is confirmed using the functional assays described above. The nucleotide and amino acid sequences of human VR1 are determined according to methods 30 well known in the art.

Example 14: Identification of human capsaicin receptor-related polypeptide VRRP-1

35 Rat VRRP-1 sequences were used to screen the Genbank database to identify capsaicin receptor-related polypeptides from other organisms. The screen identified several human and mouse EST sequences having homology to three separate regions of rat VRRP-1, which regions are termed Regions A, B, and C. Regions A, B, and C represents portions of the VRRP-1 sequence within which the human and mouse VRRP-1-encoding ESTs are clustered, listed from 5' to 3' respectively. Region A encompasses from about residue 580 to about residue 850; Region B encompasses from about

nucleotide residue 960 to about residue 1730; and Region C encompasses from about nucleotide residue 1820 to about residue 2505 in rat the VRRP-1 nucleotide sequence. A summary of the human and mouse EST sequences corresponding to each of these regions is provided in the table below.

5 **Table: Human and Mouse EST Sequences Corresponding to Rat VRRP-1**

	Rat VRRP-1 Region A (Genbank Accession Nos.)	Rat VRRP-1 Region B (Genbank Accession Nos.)	Rat VRRP-1 Region C (Genbank Accession Nos.)
Human ESTs	H20025, AA236416, H51393, AA236417, H27879, H50364, N21167, AA461295, N26729, H21490, H49060	AA281349, W44731, N23395, W38665, AA357145, N24224	W92895, T12251, AA304033, N35179, AA281348
Mouse ESTs	W82502, W53556	AA139413	AA476107, AA015295, AA274980

These human and mouse EST sequences can be used to determine a consensus nucleotide sequence for each of Regions A, B, and C. The consensus nucleotide sequence for human VRRP-1 for Region A (SEQ ID NO:5), Region B (SEQ ID NO:6), and Region C (SEQ ID NO:7) are provided in 10 the Sequence Listing below. The consensus sequences can be used to design PCR probes to isolate a fragment encoding the full-length VRRP-1 using methods that are well known in the art.

Example 15. Cloning Human VRRP-1

The rat VR1 nucleotide and protein sequences were used to search the genbank databases 15 for related entities. A number of expressed sequence tag (EST) sequences were found that exhibited homology to the rat VR1. These were from human and mouse sources. These sequences were aligned with each other and with rat VR1 and found that all but one of the human sequences appeared to encode the same protein and that this protein was highly homologous to the protein encoded by the mouse sequences. The predicted sequences of these human and mouse proteins were about 50% 20 identical to the rat VR1 protein but much more highly related to one another.

Using the human and mouse EST sequences, PCR primers were designed that were then used 25 on rat brain-derived cDNA to amplify a DNA fragment encoding most of this putative protein. This fragment was radiolabeled and used as a hybridization probe to isolate a full-length cDNA from a rat brain-derived cDNA library. The cDNA (rat VRRP-1) encodes a protein of 761 aa (SEQ ID NO:3) that is 49% identical to the rat VR1 protein and 74% identical to the human VRRP1 protein (SEQ ID NO:23) predicted from the available EST sequences. The rat VRRP-1 mRNA is expressed in sensory ganglia and in other tissues such as brain, spinal cord, spleen, lung, and large intestine.

The human and mouse EST sequences were used to design PCR primers that would allow amplification of the human VRRP-1 sequence from a human-derived cDNA source. Using cDNA derived from human CCRF-CEM cells, a fragment of the human VRRP-1 cDNA was amplified and sequenced, thereby confirming its identity with a subset of the reported EST sequences. Subsequently, 5 PCR primers directed against the 5 prime and 3 prime ends of the predicted human VRRP-1 sequence were used to amplify from CCRF-CEM-derived cDNA a DNA band of approximately 2500bp, which is the correct size for the human cDNA, as predicted by the alignment of the human EST sequences with the rat VRRP-1.

Example 16. Cloning Chicken VR1 Homologues

10 Degenerate oligonucleotides were designed based on the amino acid sequence of rat VR1. The oligonucleotides ODJ3885 and ODJ3887 corresponding to VR1 amino acid residues 638-644 and 676-682, respectively, were used as primers for polymerase chain reactions (PCR) with chick genomic DNA as template.

ODJ3885 (SEQ ID NO:28) - 5' TT(TC)AA(AG)TT(TC)AC(GATC)AT(ATC)GG(GATC)ATG

15 ODJ3887 (SEQ ID NO:29) 5' CAT(GATC)A(GA) (GATC)GC(GAT)AT(GATC)A(GA)CAT(AG)TT

Products of approximately 130 bp resulted, which were isolated and ligated into the vector pT-Adv (Clontech). The inserts in several of these plasmid clones were sequenced. The products from chick genomic DNA fell into two classes: one also corresponding to a very close homologue, and another corresponding to a somewhat more divergent homologue.

20

CVR-PCR1 (SEQ ID NO:30)

TTCAAGTTACCGATTGGGATGGGTGACCTGGATTTCATGAACATGCCAGATTAGATACTTGTATGCTTC
TGCTGCTGCTTTGTGATCCTCACCTACATCCTTGCTAACATGCTTATAGCCCTTATA

25

CVR-PCR2 (SEQ ID NO:31)

TTCAAGTTCACTATTGGGATGGGAGACCTGGAGTTACAGAGAACTACAGGTTCAAGTCTGTGTTGTCATCC
TTTGGTTCTCTATGTCATCCTACGTACATCCTGCTAACATGCTTATAGCCCTAATG

30 A 150 bp EcoRI fragment containing CVR-PCR2 was used as a hybridization probe to screen clones from a cDNA library derived from RNA isolated from chick embryonic dorsal root ganglia (DRG). Several hybridizing plasmids were identified. Two of these correspond to a probable chick orthologue of rat VR1. The insert of one of these pCVR2 was sequenced in its entirety (SEQ ID NO:24). The deduced protein sequence (SEQ ID NO:25) shows an amino acid identity to rat VR1 of 67%. Nucleotide 35 alignment of the coding regions of rat and chick VR1 cDNAs also shows 67% identity. Electrophysiological and calcium-imaging analysis of HEK293 cells transfected with pCVR2 indicate that the encoded protein responds to protons and to high doses of the vanilloid, resiniferatoxin, but not to capsaicin and to heating protocols which activate rat VR1.

40 **Example 17. Cloning of a Human Vanilloid Receptor**

A PCR reaction using ODJ3885 and ODJ3887 with human genomic DNA as template produced a 130bp product. This band was purified and cloned into pT-Adv. The inserts of several clones were

sequenced, which showed them all to encode a very close homologue or orthologue of rat VR1. The nucleotide sequence (SEQ ID NO:26) is 91% identical to the corresponding region of rat VR1. The deduced protein sequence over this 45 codon segment is identical to that of rat VR1.

Using this new alignment, additional PCR primers were designed to allow amplification of larger segments of VR1-homologous sequences from human cDNA sources. Primers ODJ4018, corresponding to VR1 amino acid residues 423- 429, and ODJ3767, which was derived from the sequence of human EST AA321554, were used in a PCR reaction using as template cDNA from human DRG.

10 ODJ4018 (SEQ ID NO:32) 5' TA(TC) TT(TC) AA(TC) TT(TC) TT(TC) GT(GATC) TA 3'

ODJ3767 (SEQ ID NO:33) 5' AAA AGG GGG ACC AGG GC 3'

15 The resulting products were separated by gel electrophoresis transferred to nylon membranes for hybridization with a 150bp probe derived from the previous PCR analysis. A hybridizing fragment of about 1100 bp was thus identified. This is the size expected to be produced by the position of these primers in the rat VR1 sequence.

20 The fragment is cloned for sequence analysis. The resulting sequence data is used to design primers for cloning a full length human cDNA corresponding to this sequence. This will be accomplished using the RACE PCR cloning method [Frohman, M.A. (1993) Methods Enzymol, 218:340-358]. This may also be carried out using primers derived from the sequence of the small PCR fragment HVR-PCR1.

25 All publications and patents mentioned in the above specification are herein incorporated by reference. Various modifications and variations of the described method and system of the invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. Indeed, various modifications of the described modes for carrying out the invention which are obvious to those skilled in molecular biology or related fields are intended to be within the scope of the following 30 claims.

35 Before the present nucleotide and polypeptide sequences are described, it is to be understood that this invention is not limited to the particular methodology, protocols, cell lines, vectors and reagents described as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to limit the scope of the present invention which will be limited only by the appended claims.

It must be noted that as used herein and in the appended claims, the singular forms "a", "and", and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a host cell" includes a plurality of such host cells and reference to "the antibody" includes

reference to one or more antibodies and equivalents thereof known to those skilled in the art, and so forth.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this invention belongs. Although any 5 methods, devices and materials similar or equivalent to those described herein can be used in the practice or testing of the invention, the preferred methods, devices and materials are now described.

All publications mentioned herein are incorporated herein by reference for the purpose of describing and disclosing, for example, the cell lines, vectors, and methodologies which are described in the publications which might be used in connection with the presently described invention. The 10 publications discussed herein are provided solely for their disclosure prior to the filing date of the present application. Nothing herein is to be construed as an admission that the inventors are not entitled to antedate such disclosure by virtue of prior invention.

EDITORIAL NOTE:

CASE FILE NO.: 91156/98

**THE FOLLOWING SEQUENCE
LISTINGS PAGES 1-24 ARE PART OF
THE DESCRIPTION, AND ARE
FOLLOWED BY CLAIM PAGES 57-59.**

SEQUENCE LISTING

<110> Julius, David J.
Caterina, Michael
Schumacher, Mark

<120> NUCLEIC ACID SEQUENCES ENCODING
CAPSAICIN RECEPTOR AND CAPSAICIN RECEPTOR-RELATED
POLYPEPTIDES AND USES THEREOF

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ccacagagga tctggaaagg atg gaa caa cgg gct agc tta gac tca gag gag 113
Met Glu Gln Arg Ala Ser Leu Asp Ser Glu Glu
1 5 10

tct gag tcc cca ccc caa gag aac tcc tgc ctg gac cct cca gac aga 161
Ser Glu Ser Pro Pro Gln Glu Asn Ser Cys Leu Asp Pro Pro Asp Arg
15 20 25

gac cct aac tgc aag cca cct cca gtc aag ccc cac atc ttc act acc 209
Asp Pro Asn Cys Pro Pro Val Lys Pro His Ile Phe Thr Thr
30 35 40

agg agt cgt acc cgg ctt ttt ggg aag ggt gac tcg gag gag gcc tct 257
Arg Ser Arg Thr Arg Leu Phe Gly Lys Gly Asp Ser Glu Glu Ala Ser
45 50 55

ccc ctg gac tgc cct tat gag gaa ggc ggg ctg gct tcc tgc cct atc 305
Pro Leu Asp Cys Pro Tyr Glu Glu Gly Leu Ala Ser Cys Pro Ile
60 65 70 75

atc act gtc agc tct gtt cta act atc cag agg cct ggg gat gga cct 353
Ile Thr Val Ser Ser Val Leu Thr Ile Gln Arg Pro Gly Asp Gly Pro
80 85 90

gcc agt gtc agg ccg tca tcc cag gac tcc gtc tcc gct ggt gag aag 401
Ala Ser Val Arg Pro Ser Ser Gln Asp Ser Val Ser Ala Gly Glu Lys

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aag aag cgc ctg act gac agc gag ttc aaa gac cca gag aca gga aag Lys Lys Arg Leu Thr Asp Ser Glu Phe Lys Asp Pro Glu Thr Gly Lys 140	145	150	545
acc tgt ctg cta aaa gcc atg ctc aat ctg cac aat ggg cag aat gac Thr Cys Leu Leu Lys Ala Met Leu Asn Leu His Asn Gly Gln Asn Asp 160	165	170	593
acc atc gct ctg ctc ctg gac gtt gcc cgg aag aca gac agc ctg aag Thr Ile Ala Leu Leu Asp Val Ala Arg Lys Thr Asp Ser Leu Lys 175	180	185	641
cag ttt gtc aat gcc agc tac aca gac agc tac tac aag ggc cag aca Gln Phe Val Asn Ala Ser Tyr Thr Asp Ser Tyr Tyr Lys Gly Gln Thr 190	195	200	689
gca ctg cac att gcc att gaa cgg cgg aac atg acg ctg gtg acc ctc Ala Leu His Ile Ala Ile Glu Arg Arg Asn Met Thr Leu Val Thr Leu 205	210	215	737
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cac cta tcc agg aag ttc acc gaa tgg gcc tat ggg cca gtg cac tcc	365	370	375	1217
His Leu Ser Arg Lys Phe Thr Glu Trp Ala Tyr Gly Pro Val His Ser				
tcc ctt tat gac ctg tcc tgc att gac acc tgt gaa aag aac tcg gtt	380	385	390	1265
Ser Leu Tyr Asp Leu Ser Cys Ile Asp Thr Cys Glu Lys Asn Ser Val				
ctg gag gtg atc gct tac agc agc agt gag acc cct aac cgt cat gac	400	405	410	1313
Leu Glu Val Ile Ala Tyr Ser Ser Ser Glu Thr Pro Asn Arg His Asp				
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Arg Phe Val Lys Arg Ile Phe Tyr Phe Asn Phe Phe Val Tyr Cys Leu				
tat atg atc atc ttc acc gcg gct gcc tac tat cgg cct gtg gaa ggc	445	450	455	1457
Tyr Met Ile Ile Phe Thr Ala Ala Ala Tyr Tyr Arg Pro Val Glu Gly				
ttg ccc ccc tat aag ctg aaa aac acc gtt ggg gac tat ttc cga gtc	460	465	470	1505
Leu Pro Pro Tyr Lys Leu Lys Asn Thr Val Gly Asp Tyr Phe Arg Val				
acc gga gag atc ttg tct gtg tca gga gga gtc tac ttc ttc cga	480	485	490	1553
Thr Gly Glu Ile Leu Ser Val Ser Gly Gly Val Tyr Phe Phe Arg				
ggg att caa tat ttc ctg cag agg cga cca tcc ctc aag agt ttg ttt	495	500	505	1601
Gly Ile Gln Tyr Phe Leu Gln Arg Arg Pro Ser Leu Lys Ser Leu Phe				
gtg gac agc tac agt gag ata ctt ttc ttt gta cag tcg ctg ttc atg	510	515	520	1649
Val Asp Ser Tyr Ser Glu Ile Leu Phe Val Gln Ser Leu Phe Met				
ctg gtg tct gtg gta ctg tac ttc agc caa cgc aag gag tat gtg gct	525	530	535	1697
Leu Val Ser Val Val Leu Tyr Phe Ser Gln Arg Lys Glu Tyr Val Ala				
tcc atg gtg ttc tcc ctg gcc atg ggc tgg acc aac atg ctc tac tat	540	545	550	1745
Ser Met Val Phe Ser Leu Ala Met Gly Trp Thr Asn Met Leu Tyr Tyr				
acc cga gga ttc cag cag atg ggc atc tat gct gtc atg att gag aag	560	565	570	1793
Thr Arg Gly Phe Gln Gln Met Gly Ile Tyr Ala Val Met Ile Glu Lys				
atg atc ctc aga gac ctg tgc cgg ttt atg ttc gtc tac ctc gtg ttc	575	580	585	1841
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Leu Phe Gly Lys Gly Asp Ser Glu Glu Ala Ser Pro Leu Asp Cys Pro
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<210> 4
 <211> 761
 <212> PRT
 <213> R. rattus

<400> 4

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 Pro Pro Met Glu Ser Pro Phe Gln Arg Glu Asp Arg Asn Ser Ser Pro
 35 40 45
 Gln Ile Lys Val Asn Leu Asn Phe Ile Lys Arg Pro Pro Lys Asn Thr
 50 55 60
 Ser Ala Pro Ser Gln Gln Glu Pro Asp Arg Phe Asp Arg Asp Arg Leu
 65 70 75 80
 Phe Ser Val Val Ser Arg Gly Val Pro Glu Glu Leu Thr Gly Leu Leu
 85 90 95
 Glu Tyr Leu Arg Trp Asn Ser Lys Tyr Leu Thr Asp Ser Ala Tyr Thr
 100 105 110
 Glu Gly Ser Thr Gly Lys Thr Cys Leu Met Lys Ala Val Leu Asn Leu
 115 120 125
 Gln Asp Gly Val Asn Ala Cys Ile Met Pro Leu Leu Gln Ile Asp Lys
 130 135 140
 Asp Ser Gly Asn Pro Lys Pro Leu Val Asn Ala Gln Cys Thr Asp Glu
 145 150 155 160
 Phe Tyr Gln Gly His Ser Ala Leu His Ile Ala Ile Glu Lys Arg Ser
 165 170 175
 Leu Gln Cys Val Lys Leu Leu Val Glu Asn Gly Ala Asp Val His Leu
 180 185 190
 Arg Ala Cys Gly Arg Phe Phe Gln Lys His Gln Gly Thr Cys Phe Tyr
 195 200 205
 Phe Gly Glu Leu Pro Leu Ser Leu Ala Ala Cys Thr Lys Gln Trp Asp
 210 215 220
 Val Val Thr Tyr Leu Leu Glu Asn Pro His Gln Pro Ala Ser Leu Glu
 225 230 235 240
 Ala Thr Asp Ser Leu Gly Asn Thr Val Leu His Ala Leu Val Met Ile
 245 250 255
 Ala Asp Asn Ser Pro Glu Asn Ser Ala Leu Val Ile His Met Tyr Asp
 260 265 270
 Gly Leu Leu Gln Met Gly Ala Arg Leu Cys Pro Thr Val Gln Leu Glu
 275 280 285
 Glu Ile Ser Asn His Gln Gly Leu Thr Pro Leu Lys Leu Ala Ala Lys
 290 295 300
 Glu Gly Lys Ile Glu Ile Phe Arg His Ile Leu Gln Arg Glu Phe Ser
 305 310 315 320
 Gly Pro Tyr Gln Pro Leu Ser Arg Lys Phe Thr Glu Trp Cys Tyr Gly
 325 330 335
 Pro Val Arg Val Ser Leu Tyr Asp Leu Ser Ser Val Asp Ser Trp Glu
 340 345 350
 Lys Asn Ser Val Leu Glu Ile Ile Ala Phe His Cys Lys Ser Pro Asn
 355 360 365
 Arg His Arg Met Val Val Leu Glu Pro Leu Asn Lys Leu Leu Gln Glu
 370 375 380
 Lys Trp Asp Arg Leu Val Ser Arg Phe Phe Asn Phe Ala Cys Tyr
 385 390 395 400
 Leu Val Tyr Met Phe Ile Phe Thr Val Val Ala Tyr His Gln Pro Ser
 405 410 415
 Leu Asp Gln Pro Ala Ile Pro Ser Ser Lys Ala Thr Phe Gly Glu Ser
 420 425 430
 Met Leu Leu Leu Gly His Ile Leu Ile Leu Leu Gly Gly Ile Tyr Leu
 435 440 445
 Leu Leu Gly Gln Leu Trp Tyr Phe Trp Arg Arg Arg Leu Phe Ile Trp
 450 455 460
 Ile Ser Phe Met Asp Ser Tyr Phe Glu Ile Leu Phe Leu Leu Gln Ala
 465 470 475 480
 Leu Leu Thr Val Leu Ser Gln Val Leu Arg Phe Met Glu Thr Glu Trp

485	490	495
Tyr Leu Pro Leu Leu Val Leu Ser Leu Val Leu Gly Trp Leu Asn Leu		
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Leu Tyr Tyr Thr Arg Gly Phe Gln His Thr Gly Ile Tyr Ser Val Met		
515	520	525
Ile Gln Lys Val Ile Leu Arg Asp Leu Leu Arg Phe Leu Leu Val Tyr		
530	535	540
Leu Val Phe Leu Phe Gly Phe Ala Val Ala Leu Val Ser Leu Ser Arg		
545	550	555
Glu Ala Arg Ser Pro Lys Ala Pro Glu Asp Asn Asn Ser Thr Val Thr		
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Glu Gln Pro Thr Val Gly Gln Glu Glu Glu Pro Ala Pro Tyr Arg Ser		
580	585	590
Ile Leu Asp Ala Ser Leu Glu Leu Phe Lys Phe Thr Ile Gly Met Gly		
595	600	605
Glu Leu Ala Phe Gln Glu Gln Leu Arg Phe Arg Gly Val Val Leu Leu		
610	615	620
Leu Leu Leu Ala Tyr Val Leu Leu Thr Tyr Val Leu Leu Leu Asn Met		
625	630	635
Leu Ile Ala Leu Met Ser Glu Thr Val Asn His Val Ala Asp Asn Ser		
645	650	655
Trp Ser Ile Trp Lys Leu Gln Lys Ala Ile Ser Val Leu Glu Met Glu		
660	665	670
Asn Gly Tyr Trp Trp Cys Arg Arg Lys Lys His Arg Glu Gly Arg Leu		
675	680	685
Leu Lys Val Gly Thr Arg Gly Asp Gly Thr Pro Asp Glu Arg Trp Cys		
690	695	700
Phe Arg Val Glu Glu Val Asn Trp Ala Ala Trp Glu Lys Thr Leu Pro		
705	710	715
Thr Leu Ser Glu Asp Pro Ser Gly Pro Gly Ile Thr Gly Asn Lys Lys		
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Asn Pro Thr Ser Lys Pro Gly Lys Asn Ser Ala Ser Glu Glu Asp His		
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 <212> DNA
 <213> H. sapiens

<400> 5

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gatcgachgg	gactctggca	atcctcagcc	cctggtaaat	gcccagtgca	cagatgacta	240
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 <212> DNA
 <213> H. sapiens

<400> 6

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tcctgcatgc	cctagtatgc	atctcggaca	actcagctga	gaacattgca	ctggtgacca	180
gcatgtatga	tgggctcctc	caagctgggg	cccgncctct	gccctaccgt	gcnagcttga	240
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tcgrrwtty	maggcacatc	ctnnsmagcg	ggrrkttca	ggactgnagc	caccttnc	360
ccgaaagttc	accgagtgg	ngctannkgg	gcctgtccgg	gntgtcgctg	tnatgacctg	420

gnnyttctnt	ggacagctgt	naggagaact	cagtgcgtga	gatcattgcc	tttcattngc	480
aaragccgn	accgacaccg	aatggtcgtt	ttggagccccc	tgaacaaact	gctgcaggn	540
gaaatggat	ctgctcatcc	ccaagttctt	cattaaacttc	ctgtgtaatc	tatntacat	600
gttcatctc	amckctgttg	cctaccatca	gcctacccng	aagaagcagg	ccgcccctca	660
cctgaaagcg	gaggttggaa	actccatgt	gctgacgggc	cacatccctt	tcctgttagg	720
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 <211> 650
 <212> DNA
 <213> H. sapiens

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cagaagccct	ggtgagccctg	agccaggatt	ggcgcggcga	agctcctaca	ggccccaatg	180
ccacagagtc	agtgcagccc	atggagggac	aggaggacga	ggcaacggg	gcccagtaca	240
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cankktcggc	actgacagct	ggagcatctg	gaagctgcag	aaagnatct	nnntgcctgg	480
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ttggcactaa	gccagatggc	agcccsatg	agcgtgg	cttcagggtn	gaggaggtga	600
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 <211> 317
 <212> DNA
 <213> H. sapiens

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 <211> 65
 <212> PRT
 <213> H. sapiens

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Ser	Ala	Gln	Pro	Glu	Glu	Val	Tyr	Leu	Arg	Gln	Phe	Ser	Gly	Ser	Leu
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Lys	Pro	Glu	Asp	Ala	Glu	Val	Phe	Lys	Ser	Pro	Ala	Ala	Ser	Gly	Glu
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Lys															
65															

<210> 10
 <211> 471
 <212> DNA
 <213> M. musculus

<400> 10

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cttcnanaaaa accaangggc ggcctggctt ctactttggt gagctgcccc tgtccctggc	360
tgcgtgcacc aaccagctgg ccatttgaa attcctgctg cagaactctt gggcagcctg	420
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 <212> DNA
 <213> M. musculus

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atgacttcaa ggctgtcttt catcatctg ttactggcct atgtgattct cacctacatc	180
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<210> 12
 <211> 18
 <212> DNA
 <213> R. rattus

<400> 12	
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<210> 13
 <211> 49
 <212> DNA
 <213> R. rattus

<400> 13	
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<210> 14
 <211> 71
 <212> PRT
 <213> R. rattus

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Ile Leu Thr Tyr Ile Leu Leu Asn Met Leu Ile Ala Leu Met Gly	
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50 55 60	
Gln Arg Ala Ile Thr Ile Leu	
65 70	

<210> 15
 <211> 57
 <212> PRT
 <213> H. sapiens

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 Glu Thr Val Asn Ser Val Ala Thr Asp
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<210> 16
 <211> 75
 <212> PRT
 <213> Caliphora

<400> 16
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 Gly Ser Tyr Ser Val Ile Asn Ile Ile Val Leu Leu Asn Met Leu Ile
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 Ala Met Met Ser Asn Ser Tyr Gln Ile Ile Ser Glu Arg Ala Asp Val
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 65 70 75

<210> 17
 <211> 75
 <212> PRT
 <213> D. melanogaster

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 Gly Ser Tyr Ser Val Ile Asn Ile Ile Val Leu Leu Asn Met Leu Ile
 35 40 45
 Ala Met Met Ser Asn Ser Tyr Gln Ile Ile Ser Glu Arg Ala Asp Val
 50 55 60
 Glu Trp Lys Phe Ala Arg Ser Gln Leu Trp Met
 65 70 75

<210> 18
 <211> 75
 <212> PRT
 <213> B. taurus

<400> 18
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 Val Lys Ala Gln His Glu Phe Thr Glu Phe Val Gly Ala Thr Met Phe
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 Gly Thr Tyr Asn Val Ile Ser Leu Val Val Leu Leu Asn Met Leu Ile
 35 40 45
 Ala Met Met Asn Asn Ser Tyr Gln Leu Ile Ala Asp His Ala Asp Ile
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 Glu Trp Lys Phe Ala Arg Thr Lys Leu Trp Met
 65 70 75

<210> 19
 <211> 61
 <212> PRT
 <213> C. elegans

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 Ile Ala Met Met Thr Arg Thr Tyr Glu Thr Ile Phe Leu
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<220>
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 Ser Ser Pro Val Phe Arg Leu Glu Thr Leu Asp Gly Gly Gln Glu Asp
 10 15 20

ggc tct gag gcg gac aga gga aag ctg gat ttt ggg agc ggg ctg cct 151
 Gly Ser Ala Asp Arg Gly Lys Leu Asp Phe Gly Ser Gly Leu Pro
 25 30 35

ccc atg gag tca cag ttc cag ggc gag gac cgg aaa ttc gcc cct cag 199
 Pro Met Glu Ser Gln Phe Gln Gly Glu Asp Arg Lys Phe Ala Pro Gln
 40 45 50

ata aga gtc aac ctc aac tac cga aag gga aca ggt gcc agt cag ccg 247
 Ile Arg Val Asn Leu Asn Tyr Arg Lys Gly Thr Gly Ala Ser Gln Pro
 55 60 65

gat cca aac cga ttt gac cga gat cgg ctc ttc aat gcg gtc tcc cgg 295
 Asp Pro Asn Arg Phe Asp Arg Asp Arg Leu Phe Asn Ala Val Ser Arg
 70 75 80 85

ggt gtc ccc gag gat ctg gct gga ctt cca gag tac ctg agc aag acc 343
 Gly Val Pro Glu Asp Leu Ala Gly Leu Pro Glu Tyr Leu Ser Lys Thr
 90 95 100

agc aag t 350
 Ser Lys

<210> 21

<211> 764
 <212> DNA
 <213> H. sapiens

<220>
 <221> CDS
 <222> (3) ... (764)

<400> 21

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1			5					10						15		
gtg	gta	agc	tac	ctc	ctg	gag	aac	cca	cac	cag	ccc	gcc	agc	ctg	cag	95
Val	Val	Ser	Tyr	Leu	Leu	Glu	Asn	Pro	His	Gln	Pro	Ala	Ser	Leu	Gln	
				20				25						30		
gcc	act	gac	tcc	cag	ggc	aac	aca	gtc	ctg	cat	gcc	cta	gtg	atg	atc	143
Ala	Thr	Asp	Ser	Gln	Gly	Asn	Thr	Val	Leu	His	Ala	Leu	Val	Met	Ile	
				35				40						45		
tcg	gac	aac	tca	gct	gag	aac	att	gca	ctg	gtg	acc	agc	atg	tat	gat	191
Ser	Asp	Asn	Ser	Ala	Glu	Asn	Ile	Ala	Leu	Val	Thr	Ser	Met	Tyr	Asp	
				50				55						60		
ggg	ctc	ctc	caa	gct	ggg	gcc	cgc	ctc	tgc	cct	acc	gtg	cag	ctt	gag	239
Gly	Leu	Leu	Gln	Ala	Gly	Ala	Arg	Leu	Cys	Pro	Thr	Val	Gln	Leu	Glu	
				65				70						75		
gac	atc	cgc	aac	ctg	cag	gat	ctc	acg	cct	ctg	aag	ctg	gcc	gcc	aag	287
Asp	Ile	Arg	Asn	Leu	Gln	Asp	Leu	Thr	Pro	Leu	Lys	Leu	Ala	Ala	Lys	
				80				85						95		
gag	ggc	aag	atc	grr	aty	ttc	aag	gca	cat	cct	tgc	aag	cgg	gaa	gtt	335
Glu	Gly	Lys	Ile	Xaa	Xaa	Phe	Lys	Ala	His	Pro	Cys	Lys	Arg	Glu	Val	
				100				105						110		
ttc	agg	act	gaa	gcc	acc	ttt	tcc	ccg	aaa	gtt	cac	cga	gtg	gtg	gct	383
Phe	Arg	Thr	Glu	Ala	Thr	Phe	Ser	Pro	Lys	Val	His	Arg	Val	Val	Ala	
				115				120						125		
aat	ggg	gcc	tgt	ccg	ggt	tgt	cgc	tgt	aat	gac	ctg	ggc	ttt	ctg	tgg	431
Asn	Gly	Ala	Cys	Pro	Gly	Cys	Arg	Cys	Asn	Asp	Leu	Gly	Phe	Leu	Trp	
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aca	gct	gtg	agg	aga	act	cag	tgc	tgg	rra	tca	ttg	cct	ttc	att	tgc	479
Thr	Ala	Val	Arg	Arg	Thr	Gln	Cys	Trp	Xaa	Ser	Leu	Pro	Phe	Ile	Cys	
				145				150						155		
aar	agc	ccg	acc	gac	acc	gaa	tgg	tgc	ttt	tgg	agc	ccc	tga	aca	aac	527
Xaa	Ser	Pro	Thr	Asp	Thr	Glu	Trp	Ser	Phe	Trp	Ser	Pro	*	Thr	Asn	
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tgc	tgc	agg	cga	aat	ggg	atc	tgc	tca	tcc	cca	agt	tct	tct	taa	act	575
Cys	Cys	Arg	Arg	Asn	Gly	Ile	Cys	Ser	Ser	Pro	Ser	Ser	Ser	*	Thr	
				175				180						185		
tcc	tgt	gta	atc	tga	tta	cat	gtt	cat	ctt	cac	cgc	tgt	tgc	cta	cca	623
Ser	Cys	Val	Ile	*	Leu	His	Val	His	Leu	His	Arg	Cys	Cys	Leu	Pro	
				190				195						200		

tca	gcc	tac	cct	gaa	gaa	gca	ggc	cgc	ccc	tca	cct	gaa	agc	gga	ggt	671
Ser	Ala	Tyr	Pro	Glu	Glu	Ala	Gly	Arg	Pro	Ser	Pro	Glu	Ser	Gly	Gly	
205				210						215				220		
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Trp	Lys	Leu	His	Ala	Ala	Asp	Gly	Pro	His	Pro	Tyr	Pro	Ala	Arg	Gly	
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Gly	Ala	Gly	Leu	Ala	Glu	Pro	Ala	Leu	Leu	Tyr	Thr	Trp	Leu	Pro	Ala	
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cac	agg	cat	cta	cag	tgt	cat	gat	cca	gaa	gcc	ctg	gtg	agc	ctg	agc	143
His	Arg	His	Leu	Gln	Cys	His	Asp	Pro	Glu	Ala	Leu	Val	Ser	Leu	Ser	
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Gln	Asp	Trp	Arg	Pro	Glu	Ala	Pro	Thr	Gly	Pro	Asn	Ala	Thr	Glu	Ser	
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gtg	cag	ccc	atg	gag	gga	cag	gag	gac	gag	ggc	aac	ggg	gcc	cag	tac	239
Val	Gln	Pro	Met	Glu	Gly	Gln	Glu	Asp	Glu	Gly	Asn	Gly	Ala	Gln	Tyr	
65						70					75					
agg	ggt	atc	ctg	gwa	gcc	tcc	ttg	gag	ctc	ttc	aaa	ttc	acc	atc	ggc	287
Arg	Gly	Ile	Leu	Xaa	Ala	Ser	Leu	Glu	Leu	Phe	Lys	Phe	Thr	Ile	Gly	
80						85				90			95			
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Met	Gly	Glu	Leu	Ala	Phe	Gln	Glu	Gln	Leu	His	Phe	Arg	Gly	Met	Val	
100						105							110			
ctg	ctg	ctg	ctg	gcc	tac	gtg	ctg	ctc	acc	tac	atc	ctg	ctg	ctc	383	
Leu	Leu	Leu	Leu	Ala	Tyr	Val	Leu	Leu	Thr	Tyr	Ile	Leu	Leu	Leu		
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aac	atg	ctc	atc	gcc	ctc	wtg	agc	gag	acc	gtc	aac	agt	gtc	gcc	act	431
Asn	Met	Leu	Ile	Ala	Leu	Xaa	Ser	Glu	Thr	Val	Asn	Ser	Val	Ala	Thr	
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Cys Phe Arg Val Glu Glu Val Asn Trp Ala Ser Trp Glu Gln Thr Leu			
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Pro Thr Leu Cys Glu Asp Pro Ser Gly Ala Gly Val Pro Arg Thr Leu			
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Tyr Leu Ser Lys Thr Ser Lys Tyr Leu Thr Asp Ser Glu Tyr Thr Glu			
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Tyr Arg Gly His Ser Ala Leu His Ile Ala Ile Glu Lys Arg Ser Leu			
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Ala Xaa			

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Pro	Asp	Gly	Ser	Pro	Asp	Glu	Arg	Trp	Cys	Phe	Arg	Val	Glu	Glu	Val
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680															
685															

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Met Ser Ser Ile Leu Glu Lys Met Lys Lys Phe Gly Ser Ser Asp Ile	
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Leu Glu Thr Ala Asp Asn Leu Gln Gly Thr Phe Ser Asn Lys Val Gln	
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Pro Ser Lys Ser Asn Ile Phe Ala Arg Arg Gly Arg Phe Val Met Gly	
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Glu Lys Ala Phe Lys Phe Tyr Asp Arg Arg Ile Phe Asp Ala Val	
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Ala Arg Gly Ser Thr Lys Asp Leu Asp Asp Leu Leu Tyr Leu Asn	
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Arg Thr Leu Lys His Leu Thr Asp Asp Glu Phe Lys Glu Pro Glu Thr	
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Ser Met Gly Asn Met Val Leu His Thr Leu Val Glu Ile Ala Asp Asn			
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Cys Arg His Leu Ser Arg Lys Phe Thr Glu Trp Ala Tyr Gly Pro Val			
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Ser Val Leu Glu Ile Ile Ala Tyr Ser Ser Glu Thr Pro Asn Arg His			

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Tyr Val Ile Leu Thr Tyr Ile Leu Leu Leu Asn Met Leu Ile Ala Leu	
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Glu Val Asn Trp Ser Thr Trp Asn Thr Asn Leu Gly Ile Ile Asn Glu	
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 Gly Lys Leu His Lys Leu Leu Ser Thr Asp Ser Ile Thr Gly Cys Ser
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Ser His Thr Lys Arg Gly Arg Thr Ser Tyr Asn Ser Leu Tyr Tyr Thr		
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Thr Glu Asn Tyr Arg Phe Lys Ser Val Phe Val Ile Leu Leu Val Leu		
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Lys Leu Gln Arg Pro Ile Thr Ile Leu Asp Ile Glu Asn Ser Tyr Leu		
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Asn Cys Leu Arg Arg Ser Phe Arg Ser Gly Lys Arg Val Leu Val Gly		
725	730	735
Ile Thr Pro Asp Gly Gln Asp Asp Tyr Arg Trp Cys Phe Arg Val Asp		
740	745	750
Glu Val Asn Trp Ser Thr Trp Asn Thr Asn Leu Gly Ile Ile Asn Glu		
755	760	765
Asp Pro Gly Cys Ser Gly Asp Leu Lys Arg Asn Pro Ser Tyr Cys Ile		
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Lys Pro Gly Arg Val Ser Gly Lys Asn Trp Lys Thr Leu Val Pro Leu		
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Leu Arg Asp Gly Ser Arg Arg Glu Glu Thr Pro Lys Leu Pro Glu Glu		
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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An isolated capsaicin receptor polypeptide.
- 5 2. The capsaicin receptor polypeptide of claim 1, wherein the polypeptide is a VR1 subtype.
- 10 3. The capsaicin receptor polypeptide of claim 1, wherein the polypeptide is a VR2 subtype.
- 15 4. The capsaicin receptor polypeptide of claim 1, wherein the polypeptide comprises an amino acid sequence selected from the group consisting of SEQ ID NO:2, 4, 9, 11, 23, 25 or 27.
- 20 5. An isolated polynucleotide sequence encoding a capsaicin receptor polypeptide of claim 1.
- 25 6. The polynucleotide sequence of claim 5, wherein the sequence encodes a VR1 subtype.
- 30 7. The polynucleotide sequence of claim 5, wherein the sequence encodes a VR2 subtype.
8. The isolated polynucleotide sequence of claim 5, wherein the sequence comprises a sequence selected from the group consisting of SEQ ID NO:1, 3, 5, 6, 7, 8, 10, 20, 21, 22, 24, or 26.
9. A recombinant expression vector comprising the polynucleotide sequence according to any one of claims 5 to 8.
- 35 10. A recombinant host cell containing the polynucleotide sequence according to any one of claims 5 to 8.
11. The recombinant host cell of claim 10, wherein said host cell is a eukaryotic cell.



12. A method for producing the capsaicin receptor polypeptide according to any one of claims 1 to 4, the method comprising the steps of:

5 a) culturing a recombinant host cell containing a capsaicin receptor polypeptide-encoding polynucleotide sequence under conditions suitable for the expression of the polypeptide; and

 b) recovering the polypeptide from the host cell culture.

13. An isolated antibody that specifically binds a capsaicin receptor polypeptide according to any one of claims 1 to 4.

10

14. A method for identifying compounds that bind a capsaicin receptor polypeptide, the method comprising the steps of:

 contacting a capsaicin receptor polypeptide according to any one of claims 1 to 4 with a test compound; and

15 detecting specific binding of the test compound to the capsaicin receptor polypeptide.

20

15. The method of claim 14, wherein said detecting is by detecting an alteration of intracellular calcium concentration in the capsaicin receptor-expressing host cell.

25

16. A method for detecting a vanilloid compound in a sample, wherein the vanilloid compound has activity in binding a capsaicin receptor polypeptide, the method comprising the steps of:

 contacting a sample suspected of containing a vanilloid compound with a eukaryotic host cell according to claim 11 expressing a capsaicin receptor polypeptide;

 detecting an alteration of a cellular response associated with capsaicin receptor activity in the capsaicin receptor-expressing host cell.

30

17. The method of claim 16, wherein the cellular response associated with capsaicin receptor activity is an increase in intracellular calcium concentration.

35

18. A pharmaceutical composition comprising a substantially purified capsaicin receptor polypeptide and a suitable pharmaceutical carrier.



19. A non-human transgenic animal model for capsaicin receptor gene function wherein the transgenic animal is characterized by having an alteration in capsaicin receptor function relative to a normal animal of the
5 same species, wherein said function is selected from the group consisting of vanilloid compound binding, vanilloid compound binding-induced calcium ion influx, vanilloid-evoked membrane current, vanilloid compound binding-induced induction of cell death, and vanilloid compound binding-induced response to heat.

10

20. A method of screening for biologically active agents that modulate capsaicin receptor function, the method comprising:

15

- a) combining a candidate agent with any one of:
 - (i) an isolated capsaicin receptor polypeptide according to any one of claims 1 to 4;
 - (ii) a host cell according to claim 11; or
 - (iii) a non-human transgenic animal according to claim 19; and
- b) determining the effect of said agent on capsaicin receptor function.

20

Dated this twenty-fourth day of October 2001

The Regents of the University of
California
Patent Attorneys for the Applicant:

F B RICE & CO



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Figure 1A

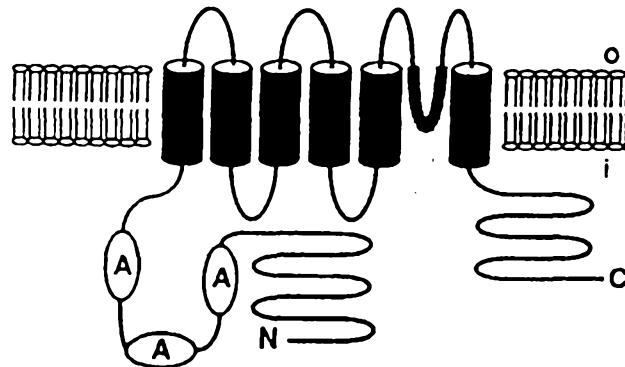


Figure 1B

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Figure 1C

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Figure 2

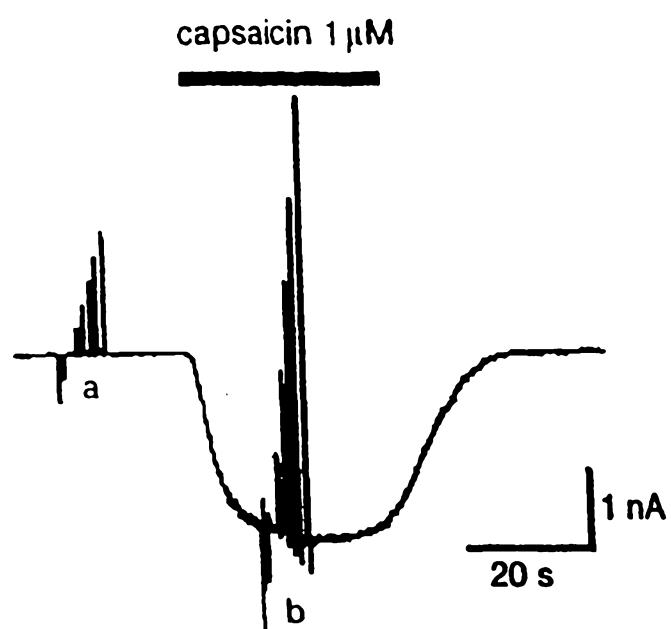
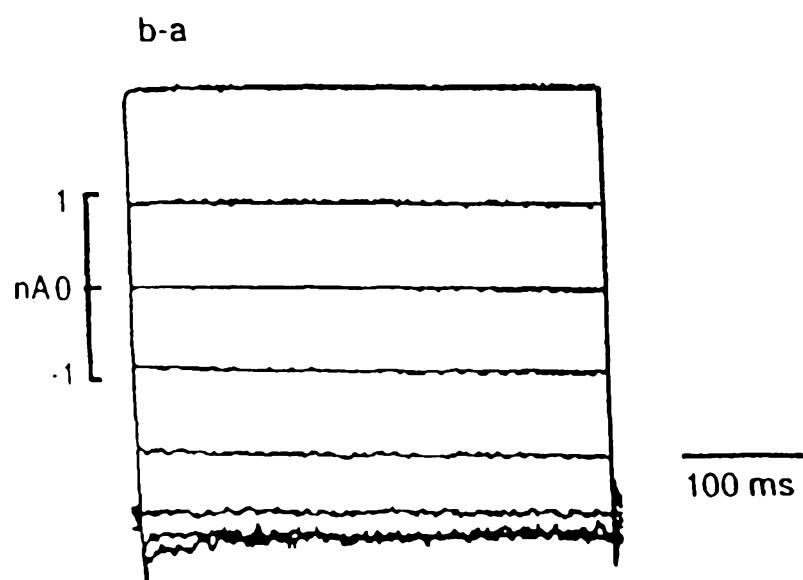


Figure 3



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Figure 4

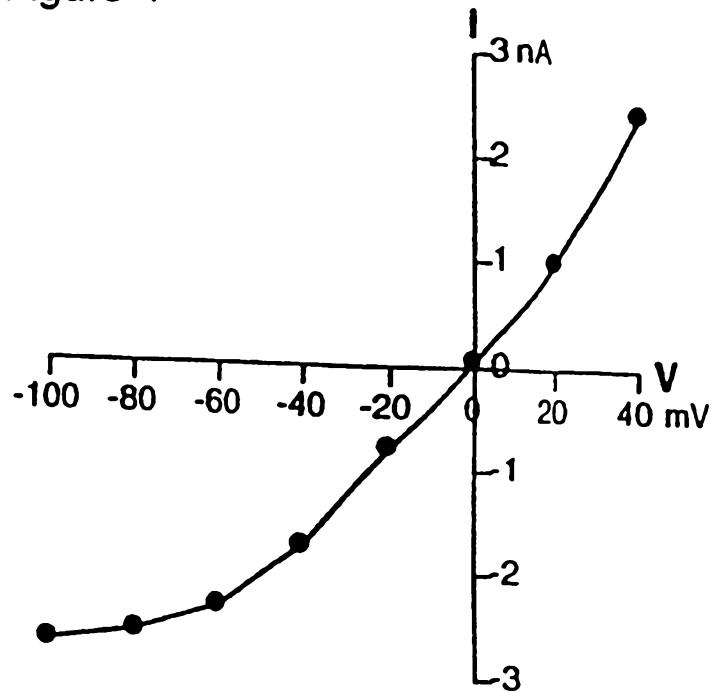
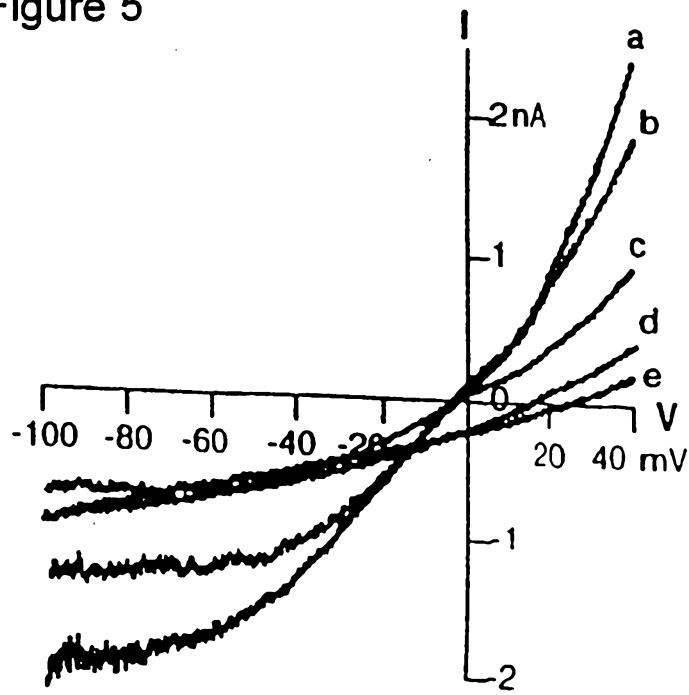
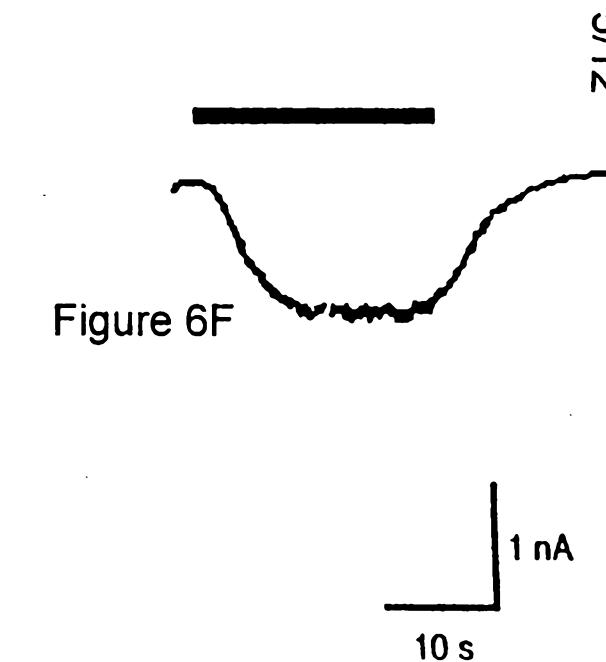
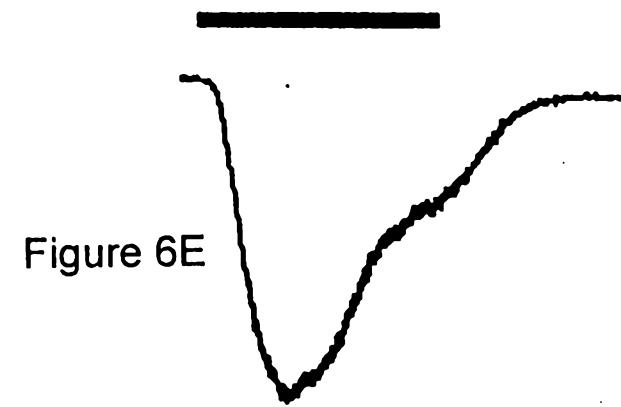
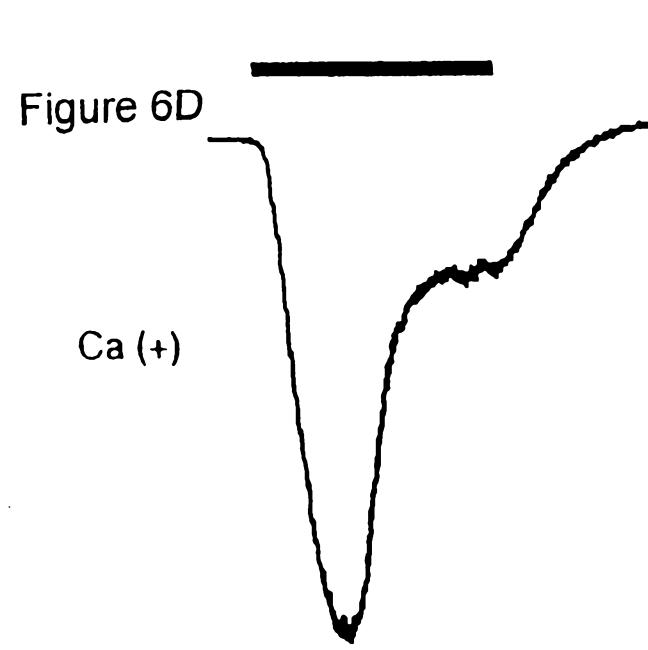
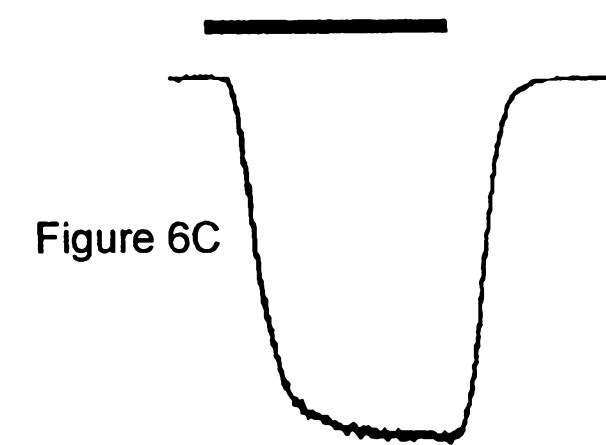
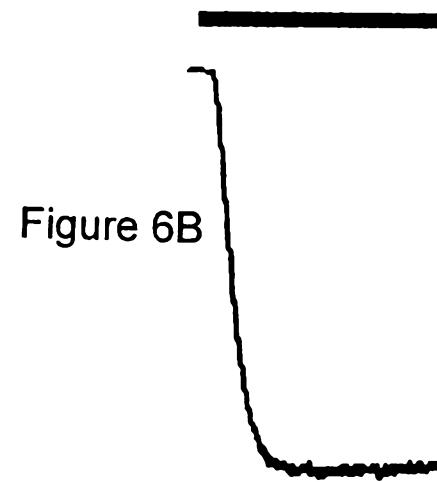
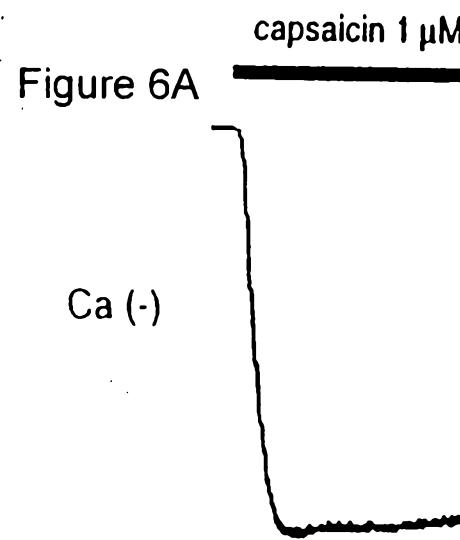


Figure 5





1 nA
10 s

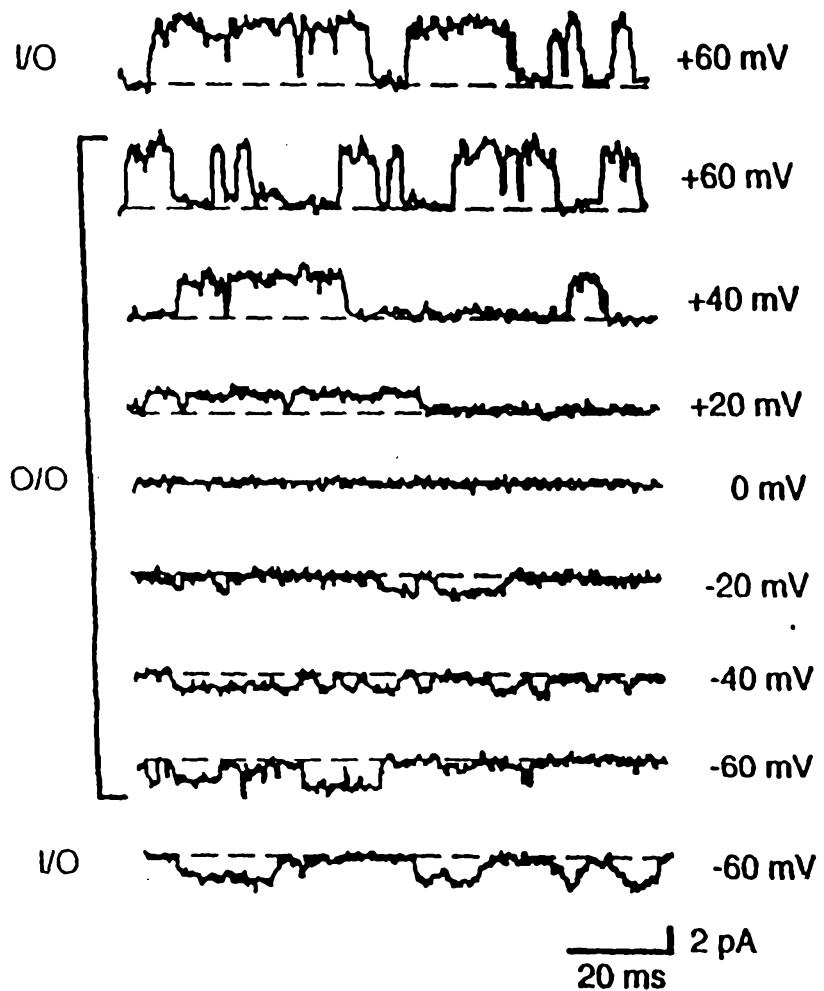


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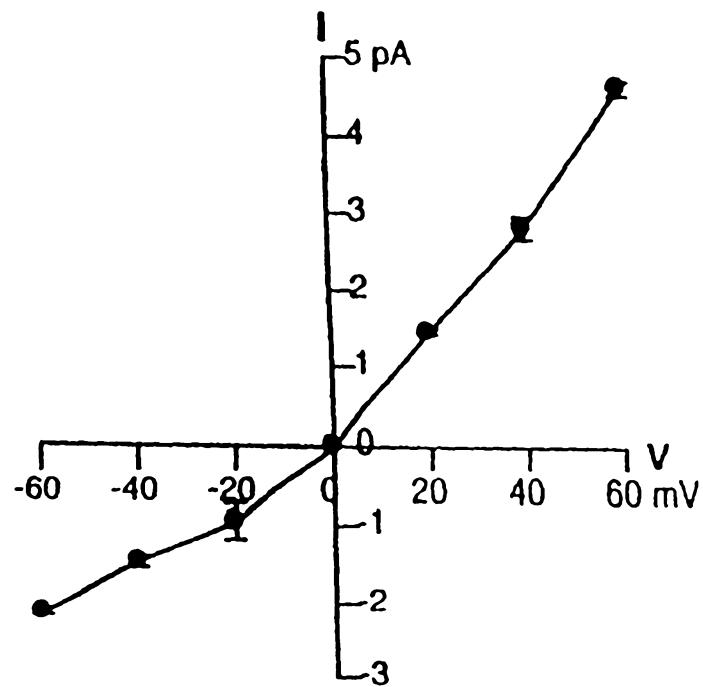


Figure 8

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Figure 9B

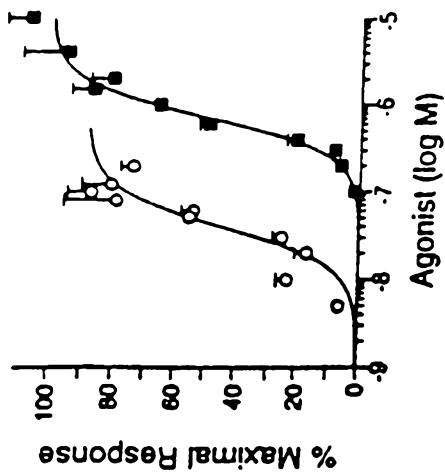


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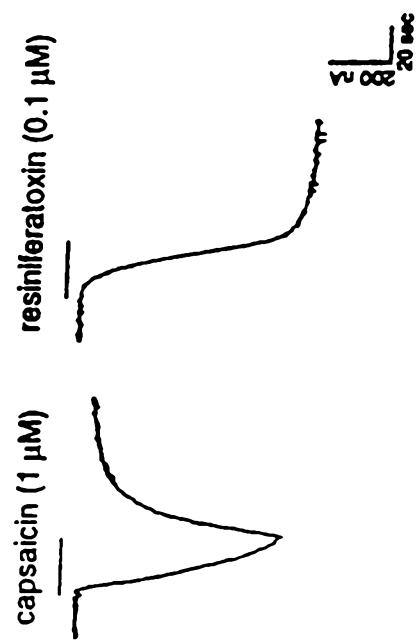


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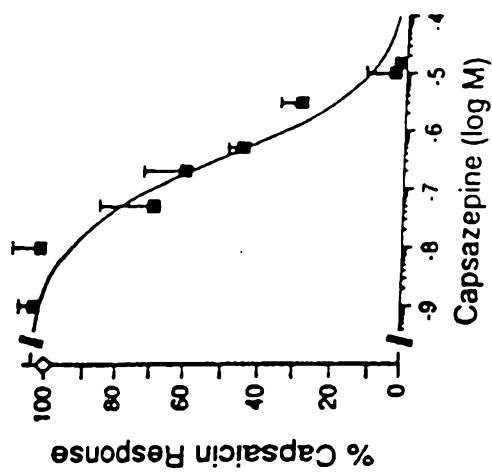
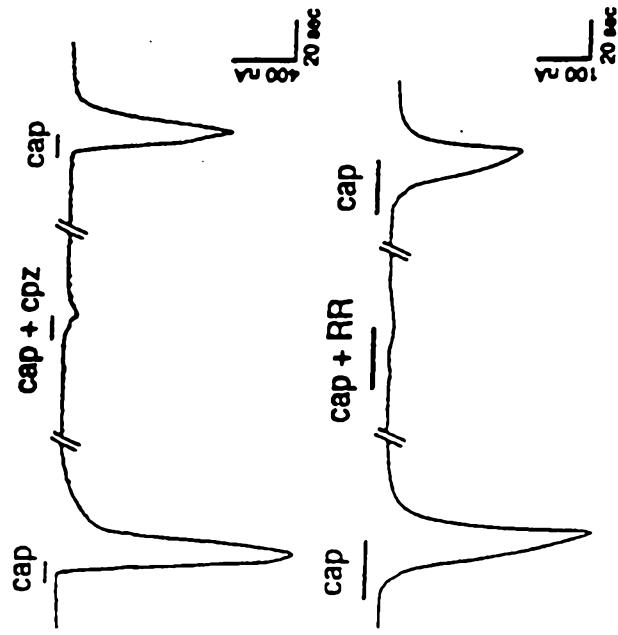
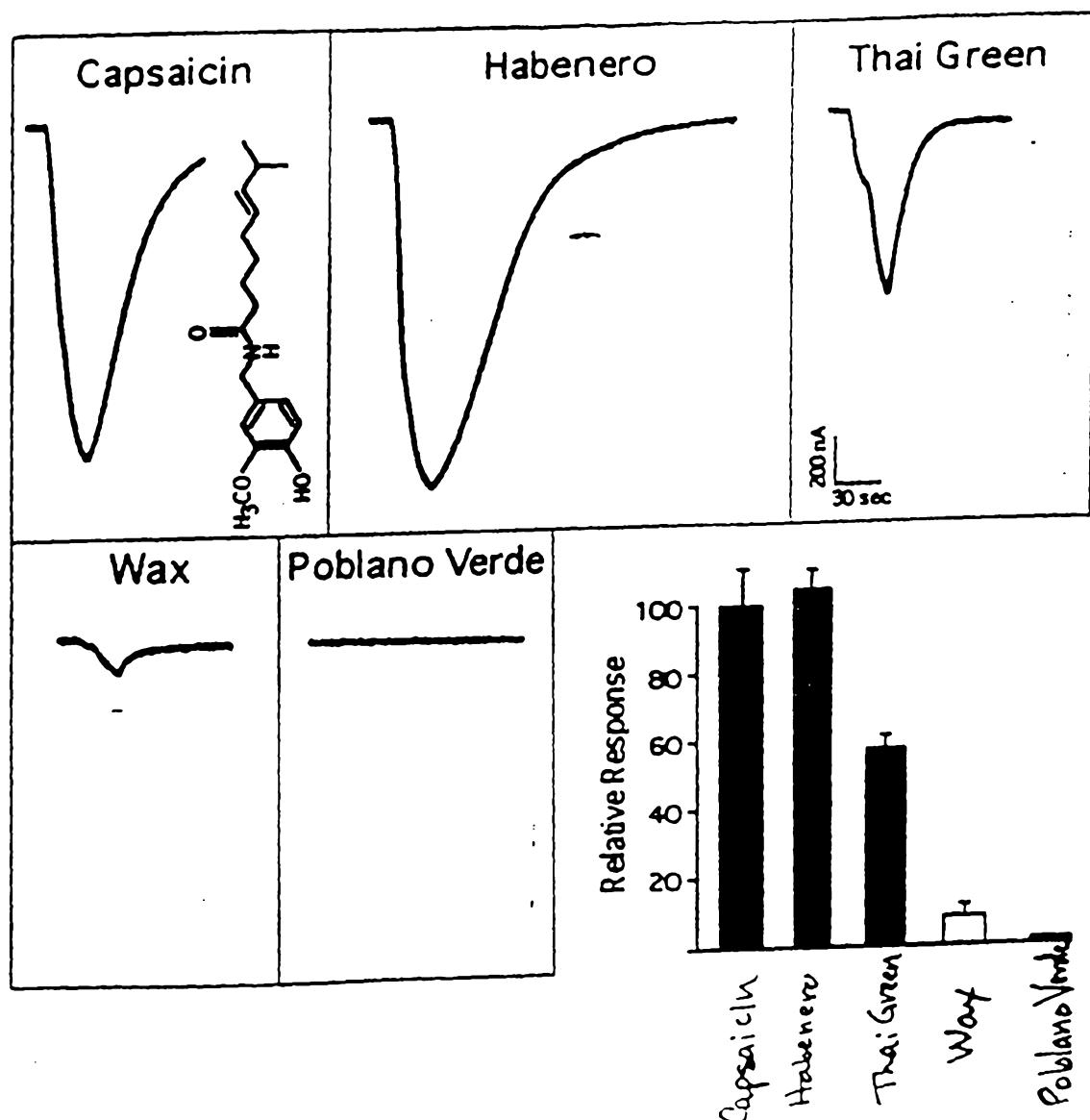


Figure 10A



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Figure 11



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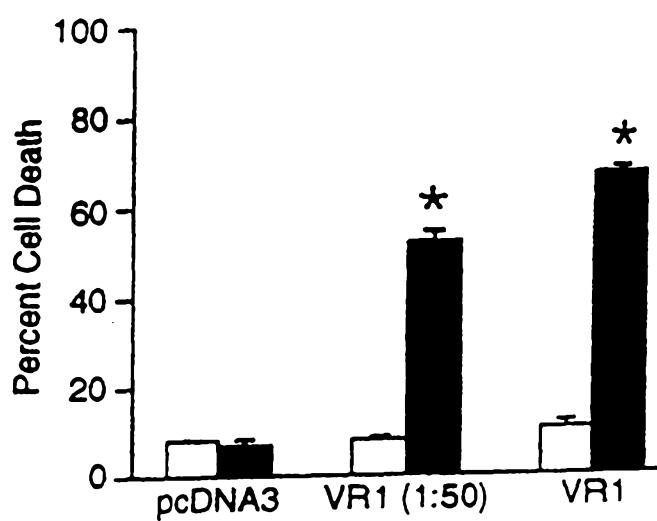


Figure 12

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Figure 14

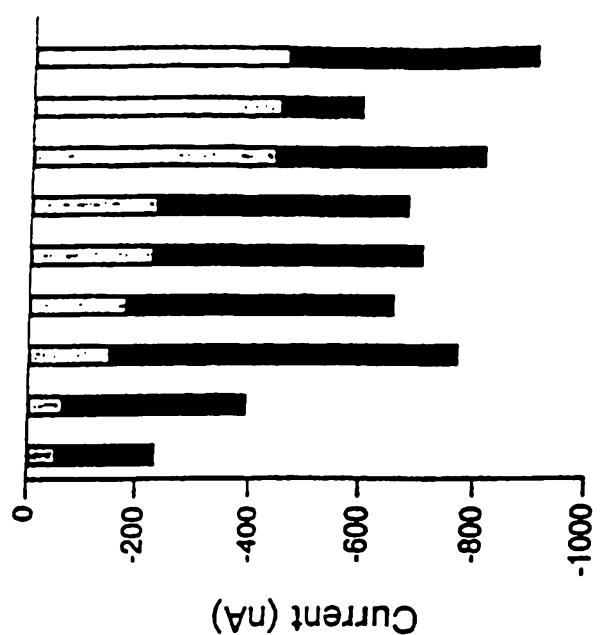
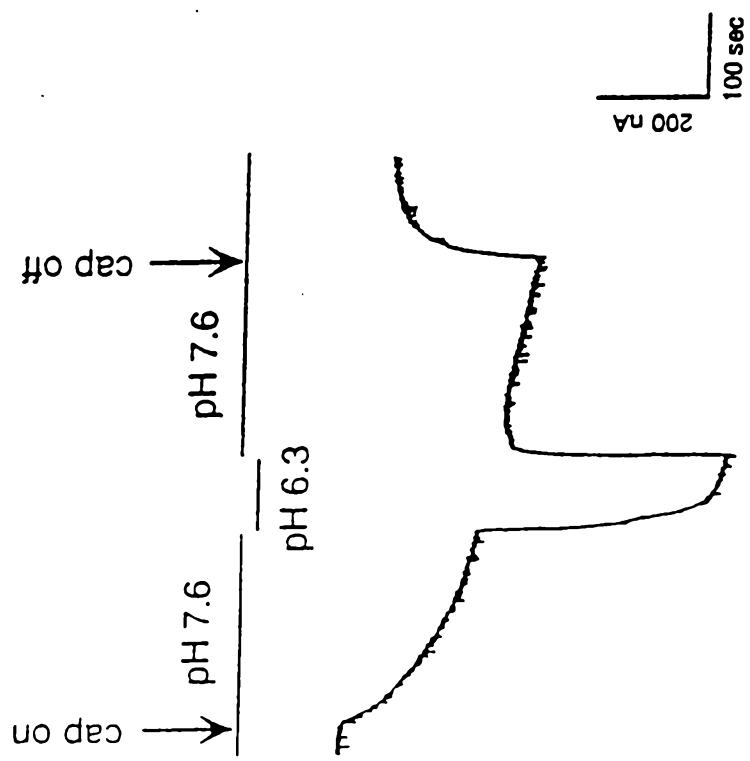
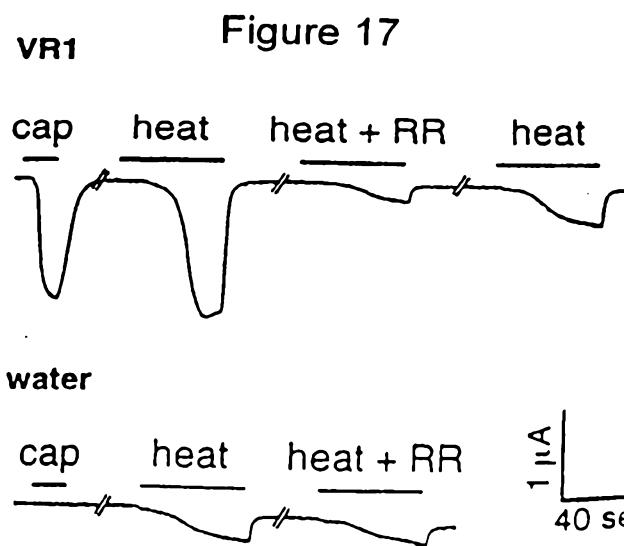
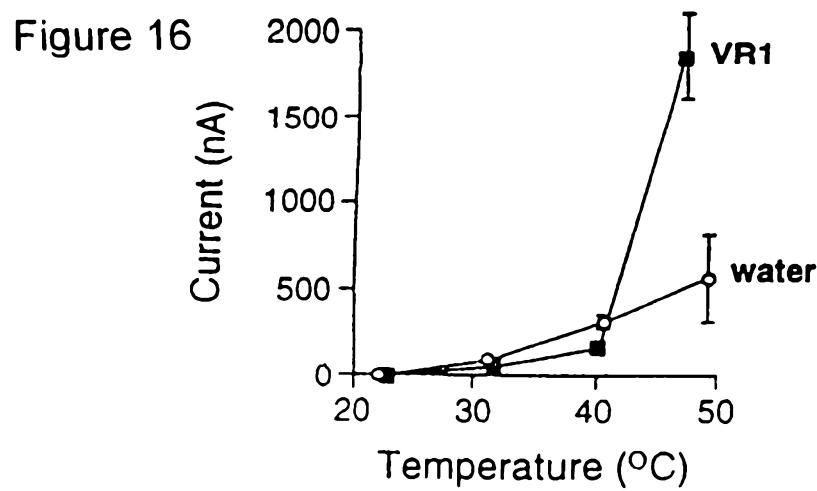
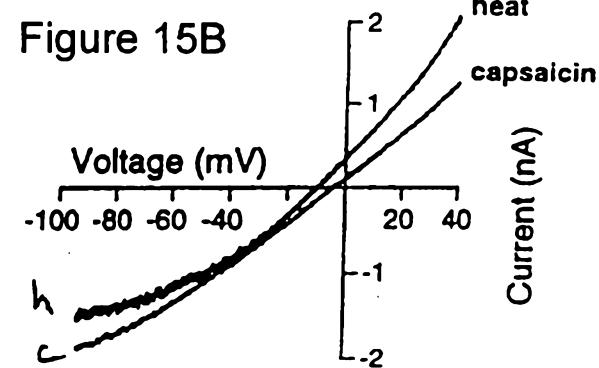
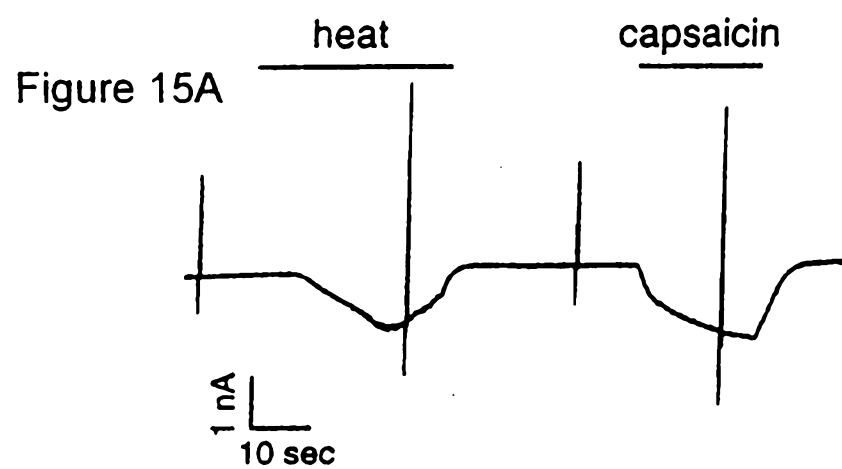


Figure 13



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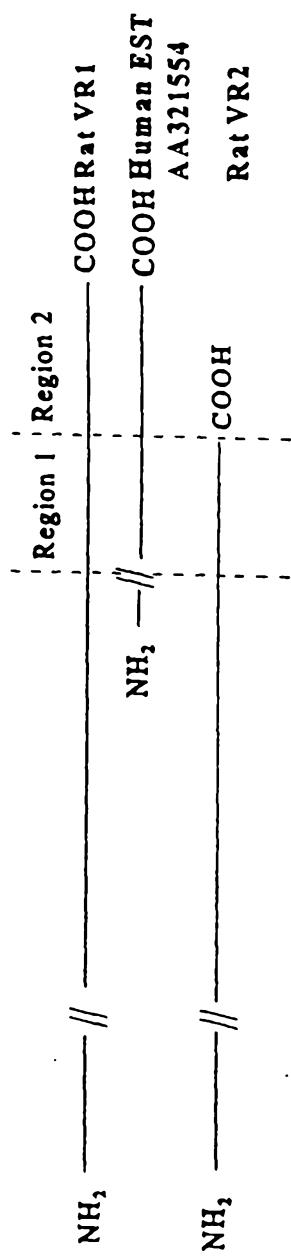


Figure 18