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## Black cohosh (*Actaea racemosa*, *Cimicifuga racemosa*) behaves as a mixed competitive ligand and partial agonist at the human mu opiate receptor

Mee-Ra Rhyu<sup>1,2,3,#</sup>, Jian Lu<sup>3</sup>, Donna E. Webster<sup>1,2,3</sup>, Daniel S. Fabricant<sup>1,2</sup>, Norman R. Farnsworth<sup>1,2</sup>, and Z. Jim Wang<sup>2,3,\*</sup>

<sup>1</sup> Department of Medicinal Chemistry and Pharmacognosy, University of Illinois, Chicago, IL 60612, USA

<sup>2</sup> UIC/NIH Center for Botanical Dietary Supplements Research, and Program for Collaborative Research in the Pharmaceutical Sciences, University of Illinois, Chicago, IL 60612, USA

<sup>3</sup> Department of Biopharmaceutical Sciences, College of Pharmacy, University of Illinois, Chicago, IL 60612, USA

### Abstract

Black cohosh is a commonly used botanical dietary supplement for the treatment of climacteric complaints. Since the opiate system in the brain is intimately associated with mood, temperature and sex hormonal levels, we investigated the activity of black cohosh extracts at the human  $\mu$  opiate receptor (hMOR) expressed in Chinese hamster ovary cells. The 100% methanol-, 75% ethanol- and 40% 2-propanol- extracts of black cohosh effectively displaced the specific binding of [<sup>3</sup>H]DAMGO to hMOR. Further studies of the clinically used ethanol extract indicated that black cohosh acted as a mixed competitive ligand, displacing  $77 \pm 4\%$  [<sup>3</sup>H]DAMGO to hMOR ( $K_i = 62.9 \mu\text{g/ml}$ ). Using the [<sup>35</sup>S]GTP $\gamma$ S assay, the action of black cohosh was found to be consistent with an agonist, with an  $EC_{50}$  of  $68.8 \pm 7.7 \mu\text{g/ml}$ . These results demonstrate for the first time that black cohosh contains active principle(s) that activate hMOR, supporting its beneficial role in alleviating menopausal symptoms.

### Keywords

black cohosh; menopause; hot flashes; opiate; botanical dietary supplement

### INTRODUCTION

*Actaea racemosa* L. or *Cimicifuga racemosa* (L.) Nutt. (Ranunculaceae), commonly known as black cohosh, has been traditionally used for gynecologic and pain disorders. The first medicinal use of black cohosh is generally attributed to Native Americans, who used black cohosh for the treatment of a variety of disorders, including various conditions unique to women such as amenorrhea and menopause, rheumatism, kidney disorders, malaise, and pain during menses and childbirth (1,2). Use of black cohosh was accepted and popularized by eclectic medical practitioners in the late 19<sup>th</sup> and early 20<sup>th</sup> centuries. Dr. John King made a significant contribution publicizing the use of black cohosh, or as he referred to it, *Macrotys*. King claimed that *Macrotys* was a remedy of “abnormal conditions of the principal organs of

\*Corresponding author: Z. Jim Wang, Ph.D., Department of Biopharmaceutical Sciences, University of Illinois, 833 South Woods Street, Chicago, IL 60612, US A, (312)996-0888 (voice), (312) 996-0098 (fax), zjwang@uic.edu.

#Visiting from The Food Function Research Division, Korea Food Research Institute, Gyeonggi-Do 463-420, Korea

reproduction in the female”, and the roots “very efficacious in the treatment of chronic ovaritis, endometriosis, and menstrual derangements, such as amenorrhea, dysmenorrhea” (1). Black cohosh root was an official drug (under the name “black snakeroot”) in the United States Pharmacopoeia (USP) from 1820 to 1926.

With a shift toward evidence-based modern medicine, the use of black cohosh in America faded by the 1930’s. However, its medicinal use gained popularity in Europe, especially in Germany, since the 1950’s. Black Cohosh is one of the main herbs recommended in Germany for menopause, PMS and secondary amenorrhoea (3). In Europe, black cohosh is commonly prescribed as an alternative to hormone replacement therapy for menopause (4). Over the past decade or so, black cohosh also regained its popularity for alleviating menopausal symptoms in the United States. The North American Menopause Society (NAMS) recommends the short term (less than 6 months) use of a black cohosh supplement for menopause (5). A number of clinical trials have been carried out to examine the efficacy and safety of black cohosh (6–11). Black cohosh appears to be effective in reducing hot flashes and depression, although more clinical evidence is still needed (12–17).

The mechanism for the effectiveness of black cohosh in treating menopausal symptoms is not entirely clear. Black cohosh was initially thought to contain formononetin, an estrogenic isoflavone (18–20). However, more recent studies have not found significant estrogenic constituents or activity (21–25). Since there are significant CNS manifestations in menopause and a tight connection between sex hormones and CNS receptors (26–28), it is plausible that black cohosh extracts may interact with CNS systems for at least some of the beneficial effects in treating menopausal symptoms. Indeed, it has been reported that black cohosh acted as an agonist at the 5HT<sub>1A</sub>, ID and 7 receptors (29), and may also have affinity to the dopamine D<sub>2</sub> receptor (20). Since the opioid system, especially the  $\mu$  opiate receptor, is essential for temperature and hormone homeostasis, this may be one of the mechanisms for the action of black cohosh in menopause. In this study, we examined three different black cohosh extracts in  $\mu$  opiate receptor binding and functional assays.

## MATERIALS AND METHODS

### Chemicals

Guanosine 5'-diphosphate (GDP), guanosine 5'-[ $\gamma$ -thio] triphosphate (GTP $\gamma$ S), bovine serum albumin (BSA), dithiothreitol (DTT), disodium ethylenediamine tetraacetate (EDTA), 4-(2-Hydroxyethyl) piperazine-1-ethanesulfonic acid N-(2-Hydroxyethyl) piperazine-N'-(2-ethanesulfonic acid) (HEPES) were obtained from Sigma (St. Louis, MO). [D-Ala<sup>2</sup>, N-MePhe<sup>4</sup>-Gly-ol<sup>5</sup>] enkephalin (DAMGO), and [<sup>3</sup>H]DAMGO were from Multiple Peptide Systems (San Diego, CA). [<sup>35</sup>S]GTP $\gamma$ S was purchased from Amersham Biosciences (Piscataway, NJ). All other chemicals were purchased from Sigma (St. Louis, MO).

### Plant materials

Black cohosh extracts were prepared and characterized as previously described (29–31). Briefly, black cohosh rhizomes/roots were provided by PureWorld Botanicals, Inc. (South Hackensack, NJ; lot number: 9-1744) (29), and were botanically verified by the UIC/NIH Center for Botanical Dietary Supplements Research and characterized by PCR (30). A voucher specimen (BC001) has been deposited at the Program for Collaborative Research in the Pharmaceutical Sciences (PCRPS), University of Illinois at Chicago. Milled roots/rhizomes of black cohosh were separately extracted by percolation with 75% ethanol (CR-ethanol), 100% methanol (CR-methanol), or 40% 2-propanol (CR-isopropanol) and then dried to a powder *in vacuo*. These extracts were chemically characterized by HPLC and standardized to active triterpene glycosides (31). The HPLC method has since been adopted by the USP-NF. The

75% ethanol extract, chemically standardized to 5.6% active triterpene glycosides and biologically standardized to 5HT7 receptor, is currently being used in a four arm randomized double-blind and placebo-controlled Phase II clinical trial that is being conducted by the UIC/NIH Center for Botanical Dietary Supplements Research. Extensive effort has been carried out to identify the active principles in black cohosh extracts, which have so far yielded a number of new compounds (32–37). For pharmacological assays, the dried extracts were dissolved in DMSO. The final DMSO concentrations in all assays were below 0.5%, which was found not to interfere with either the receptor binding or GTP $\gamma$ S binding assay.

### Cell culture

Chinese hamster ovary (CHO) cells stably transfected with human mu opioid receptors (CHO-hMOR) were established as described previously (38). CHO-hMOR cells were cultured in Dulbecco's modified eagle medium (DMEM) and Ham's F-12 medium (1:1) supplemented with 10% newborn calf serum, 100 IU/ml penicillin and 100 ( $\mu$ g/ml streptomycin. To maintain stable selection, 200 ( $\mu$ g/ml G418 was added to the growth medium. Cells were cultured in an incubator maintained at 37°C with 5% CO<sub>2</sub> in humidified air.

### Receptor binding assay

Receptor binding assay was carried out as previously described (38–40). Briefly, membranes from CHO-hMOR cells were prepared by Polytron homogenization at setting 6 for 2 min on ice, followed by centrifugation at 20,000 g for 30 min at 4°C. Protein content was determined by the Coomassie protein assay method (Pierce Biotechnology, Rockford, IL) using bovine serum albumin as the standard. For receptor binding assay, the receptor membranes (50  $\mu$ g protein/reaction) were incubated with a series of concentrations of [<sup>3</sup>H]D-Ala<sup>2</sup>,N-Me-Phe<sup>4</sup>-Gly<sup>5</sup>-ol]enkephalin (DAMGO, 1 nM) and different concentrations of black cohosh extracts in 50 mM Tris buffer (pH 7.4) at 30°C for 1 h. Nonspecific binding was determined in the presence of 20  $\mu$ M unlabelled DAMGO. Reactions were terminated by rapid vacuum filtration through GF/B filters presoaked with 0.2% polyethylenimine. Filter-bound radioactivity was determined by liquid scintillation counting (Beckman Coulter Inc., Fullerton, CA). Results, expressed in Mean  $\pm$  SD, were analyzed using the Prism program (GraphPad Software, San Diego, CA).

### Kinetics of receptor binding

The mode of receptor binding by black cohosh extract was further characterized to determine full vs partial, competitive, uncompetitive, vs noncompetitive binding to the ( $\mu$  opiate receptor. To obtain *K<sub>d</sub>* and *K<sub>i</sub>* values, [<sup>3</sup>H]DAMGO ranging from 0.1~4 nM and black cohosh ethanol extract ranging from 0 ~ 200  $\mu$ g/ml were used in the receptor binding assay as described above. Data were further transformed into a double-reciprocal plot to determine the mechanism of receptor-ligand interaction.

### [<sup>35</sup>S]Guanosine 5'-[ $\gamma$ -thio]triphosphate (GTP $\gamma$ S) binding assay

Since the  $\mu$ -opiate receptor is a G protein coupled receptor, we employed the GTP $\gamma$ S binding assay to determine the activation of the receptor. The [<sup>35</sup>S]GTP $\gamma$ S binding assay was performed based on the method previously described (38,39). Briefly, cell membranes (40  $\mu$ g protein) were incubated with 0.1 nM [<sup>35</sup>S]GTP $\gamma$ S in the reaction buffer (50 mM HEPES, 100 mM sodium chloride, 1 mM EDTA, 5 mM magnesium chloride, 30  $\mu$ M GDP, 1 mM DTT, and 0.1% BSA, pH 7.4) in the presence or absence of black cohosh extracts or DAMGO, at 30°C for 1h. The basal level was defined as the amount of [<sup>35</sup>S]GTP $\gamma$ S bound in the absence of any agonist. Non-specific binding was determined in the presence of 10  $\mu$ M unlabeled GTP $\gamma$ S. Reactions were terminated by rapid filtration and filter-bound radioactivity was determined as described above.

## Data and statistical analysis

Data, expressed as mean  $\pm$  SD, were analyzed using the GraphPad Prism program to obtain  $IC_{50}$ , maximum inhibition,  $EC_{50}$ , and  $E_{max}$  values. The dissociation constant  $K_i$  was determined using the method of Cheng and Prusoff (41). Differences in responses between groups were determined using ANOVA followed by Student's *t* (two groups) or Dunnett's *t* (multiple groups) tests.

## RESULTS

### Affinity of black cohosh extracts to the $\mu$ opiate receptor

Three different black cohosh extracts, a 75% ethanol extract, a 100% methanol extract, and a 75% isopropanol extract, were subject to a receptor binding assay to determine their affinity to the human  $\mu$  opiate receptor (hMOR). [ $^3H$ ]DAMGO, a  $\mu$  opiate receptor-specific radioligand that binds to the receptor with a high affinity (38), was used in the assay. All three extracts were able to displace the specific binding of [ $^3H$ ]DAMGO to hMOR (Fig. 1), indicating that black cohosh contains constituents with an affinity to the receptor. As expected, the affinity of black cohosh extracts is concentration-dependent. The 75% ethanol extract of black cohosh (CR-ethanol) appeared to be most effective. This is also the extract that is used in a Phase II clinical trial that is being conducted by the UIC/NIH Center for Botanical Dietary Supplements Research. We further characterized CR-ethanol in receptor binding and functional assays.

To obtain the dissociation rate constant ( $K_i$ ), different concentrations of CR-ethanol, ranging from 0.001 – 300  $\mu$ /ml, were tested in the competition binding assay against [ $^3H$ ]DAMGO (1 nM). The extract dose-dependently displaced the specific binding of [ $^3H$ ]DAMGO, with a  $K_i$  value of 62.9  $\mu$ g/ml ( $IC_{50}$ : 165.9  $\mu$ g/ml) (Fig 2). At the highest concentration used, the extract displaced  $77 \pm 4\%$  of [ $^3H$ ]DAMGO binding, indicating the black cohosh extract had strong affinity to hMOR.

### Mechanism of receptor binding

To investigate whether the black cohosh extract functions as a competitive, noncompetitive, uncompetitive, or mixed inhibitor of ligand binding to hMOR, radioligand receptor saturation binding assay was carried out using [ $^3H$ ]DAMGO (0.1–4 nM) in the absence or presence of 100 and 200  $\mu$ g/ml of CR-ethanol. Black cohosh significantly inhibited the saturation binding of DAMGO to hMOR, and as a result, the maximum binding  $B_{max}$  was decreased by 41% and 68% with 100 and 200  $\mu$ g/ml CR-ethanol respectively (Fig 3A). The apparent  $K_d$  of DAMGO for hMOR was increased 1.2 and 4.4 fold in the presence 100 and 200  $\mu$ g/ml of CR-ethanol, respectively (Table 1). Further analysis using a double-reciprocal plot indicated that the data fit best with a mixed competition mode where the hMOR-bound constituent(s) in black cohosh not only bind to the receptor binding site of hMOR alone but can also bind in the presence of DAMGO. A schematic model for black cohosh acting as a mixed competitive ligand (I) for the binding of DAMGO to hMOR is illustrated in Fig. 4.

### Activation of the human $\mu$ opiate receptor by black cohosh extract

It is critical to ascertain if the black cohosh extracts contain agonistic or antagonistic opiate activity at the receptor. The  $\mu$  opiate receptor belongs to the superfamily of G protein-coupled receptors. Activation of hMOR leads to the activation of G proteins and subsequent cellular signaling. The efficacy of a hMOR agonist in activating G-proteins, which can be measured by [ $^{35}S$ ]GTP $\gamma$ S binding to the cytoplasmic membranes (39), can be used to determine the agonist's activity at the receptor. Therefore, we employed the GTP $\gamma$ S binding assay to determine the mode of action of CR-ethanol. The extract dose-dependently activated hMOR as revealed by the significant stimulation of GTP $\gamma$ S binding to CHO-hMOR (Fig. 5). The

maximum effect was  $162.2 \pm 14.7\%$ , which was lower than that of DAMGO, a full agonist of hMOR ( $p < 0.05$ ). The  $EC_{50}$  of CR-ethanol was estimated to be  $68.8 \pm 7.7 \mu\text{g/ml}$  ( $N = 3$ ). These data suggest that the black cohosh extract contains active constituent(s) that act as an agonist at the human  $\mu$  opiate receptor, which is consistent with its beneficial action in relieving at least some of the menopausal symptoms.

## DISCUSSION

A large segment of the female population is affected by menopausal symptoms. Limited treatment options are available. Hormone replacement therapy is effective in treating hot flashes and other symptoms. However, the Women's Health Initiative and long-term follow-up from the Heart and Estrogen/progestin Replacement Study found an increased risk of cardiovascular disease, breast cancer, and stroke among women randomized to hormone therapy (42–45). Many women have turned to botanical dietary supplements for the relief of menopausal symptoms. Black cohosh is one of the most commonly used botanical dietary supplements for alleviating menopausal symptoms. Despite the long history and wide use, its mechanisms of action are still not entirely understood.

Early studies have examined the phytoestrogens contained in black cohosh (18–20). However, more recent studies did not find significant estrogenic constituents or activity (21–25,29). Since there are significant CNS manifestations in menopause and tight connection between sex hormone and the CNS receptors (26–28), it has been proposed that black cohosh may act centrally (20,29).

The current study demonstrated for the first time that black cohosh extracts contained constituents that have significant affinity to the human  $\mu$  opiate receptor. Moreover, a clinically used 75% ethanol extract of black cohosh acted as a partial agonist at the receptor.

The opiate receptor system affects several aspects of female reproductive neuroendocrinology, such as the control of sex hormones and the display of lordosis behavior (28,46–51). In fact, a decreased  $\beta$ -endorphin level is considered a hormonal marker for menopause (27). Hot flashes, a major complaint of menopausal women, are hypothesized to be caused by an erroneous setting of body core temperature (52). The CNS temperature control center is regulated by the endogenous opiate system as well as catecholamines (26,27,53). Opiates can therefore alter core temperature setting directly or indirectly by affecting the release and levels of catecholamines (27,54,55). Striking similarities exist between opiate withdrawal and menopausal hot flashes (56). Not surprisingly, opiate dependence withdrawal has been used as an animal model of menopausal hot flashes (57).

Therefore, botanical dietary supplements containing opiate activity are expected to have beneficial effects in relieving menopausal symptoms, including reducing hot flashes. The opiate agonistic activity of black cohosh may explain at least in part its efficacy in alleviating menopausal symptoms.

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## Abbreviations used

<b>CHO</b>	Chinese hamster ovary
<b>CR-ethanol</b>	a 75% ethanol extract of black cohosh
<b>CR-methanol</b>	a 100% methanol extract of black cohosh
<b>CR-isopropanol</b>	a 40% 2-propanol extract of black cohosh
<b>DAMGO</b>	[D-Ala <sup>2</sup> ,N-Me-Phe <sup>4</sup> -Gly <sup>5</sup> -ol]enkephalin
<b>DTT</b>	dithiothreitol
<b>HEPES</b>	4-(2-Hydroxyethyl) piperazine-1-ethanesulfonic acid N-(2-Hydroxyethyl) piperazine-N'-(2-ethanesulfonic acid)
<b>hMOR</b>	human $\mu$ -opiate receptor

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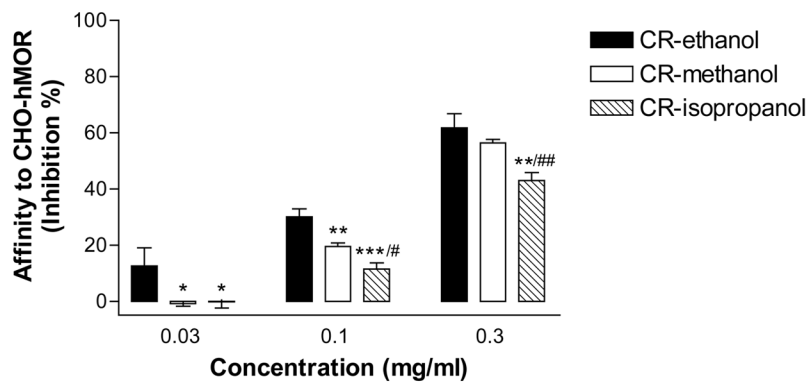
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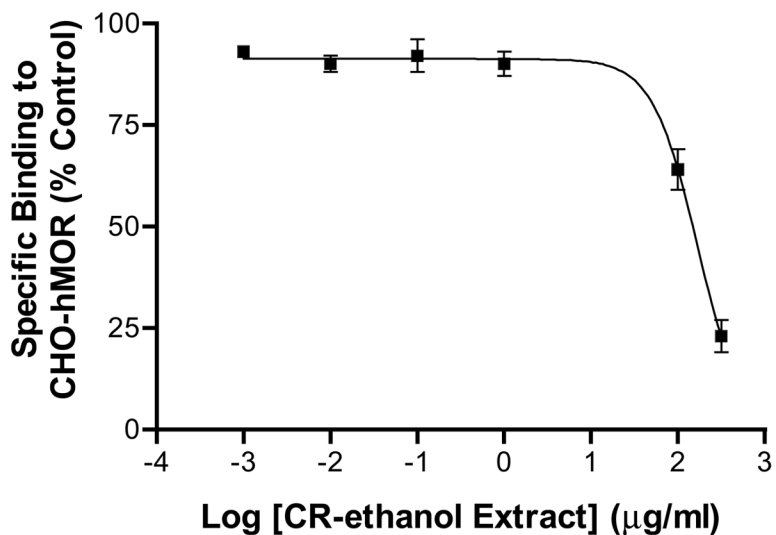


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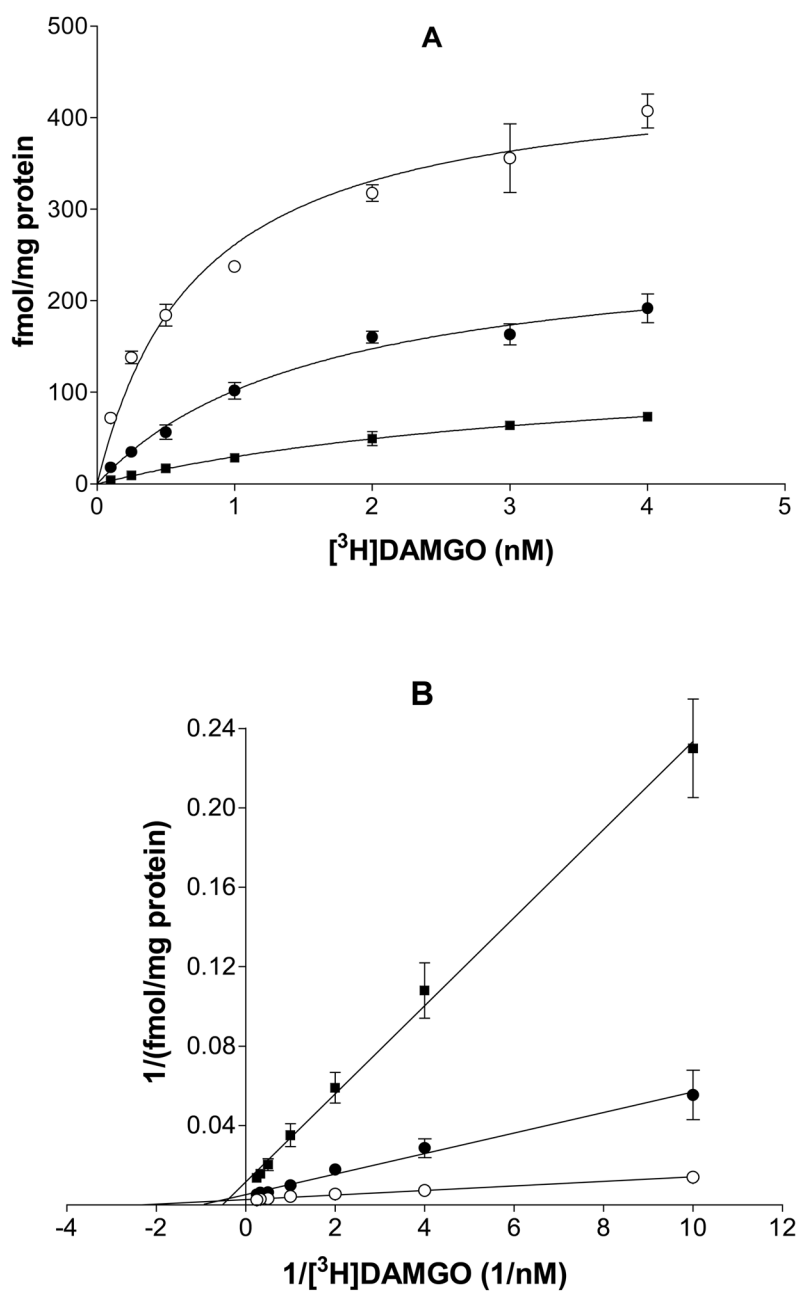
**Figure 1. Affinity of black cohosh extracts to the human  $\mu$  opiate receptor (hMOR) expressed in Chinese hamster ovary (CHO) cells**

Three black cohosh extracts, 100% methanol (CR-methanol), 75% ethanol (CR-ethanol), or 40% 2-propanol (CR-isopropanol), were used to displace the binding of [ $^3$ H]DAMGO, a selective hMOR agonist, to CHO-hMOR cells. The affinities of these extracts, at three different concentrations (0.03, 0.1, and 0.3 mg/ml), were compared. The percentage inhibition of the specific radioactivity of [ $^3$ H]DAMGO bound to the CHO-hMOR cell membranes was shown. Data are the mean  $\pm$  SD (N = 3). \*  $P < 0.05$ , \*\*  $P < 0.01$ , \*\*\*  $P < 0.001$ , compared with CR-ethanol; #  $P < 0.05$ , \*\*  $P < 0.01$ , comparison between CR-methanol and CR-isopropanol.

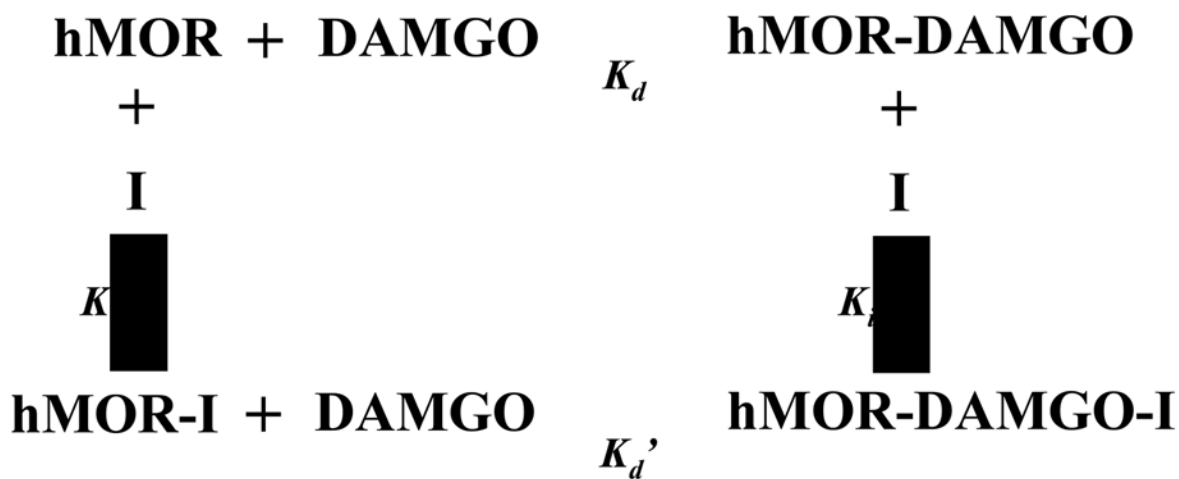


**Figure 2.**

Displacement of [<sup>3</sup>H]DAMGO binding by a clinically used 75% ethanol extract of black cohosh (CR-ethanol). CR-ethanol (0.01 – 300 µg/ml) was used to dose-dependently compete for the binding of [<sup>3</sup>H]DAMGO (1 nM) to the CHO-hMOR cell membranes. The specific radioactivity of [<sup>3</sup>H]DAMGO bound to hMOR in the absence of black cohosh was set to 100%. Each point represents the mean ± SD (N = 3). The  $K_i$  and  $IC_{50}$  values were estimated to be 62.9 µg/ml and 165.9 µg/ml, respectively.

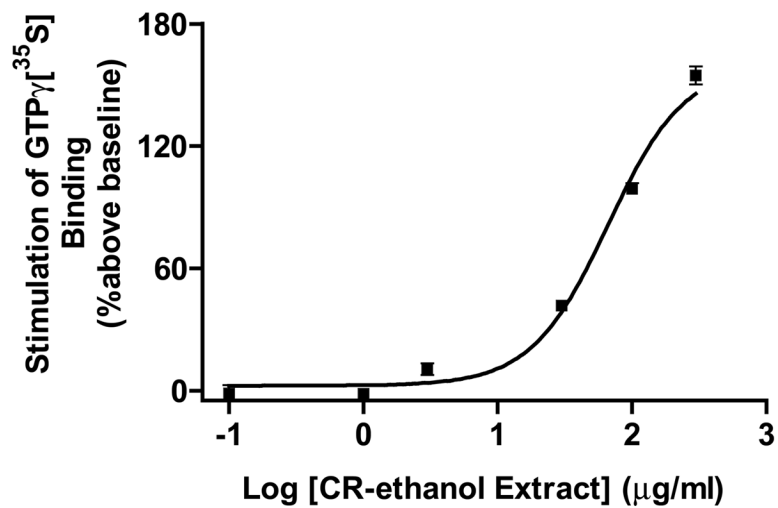


**Figure 3.** Inhibition of black cohosh on the specific binding of  $[^3\text{H}]\text{DAMGO}$  to hMOR. (A) Saturation binding of  $[^3\text{H}]\text{DAMGO}$  to hMOR in the absence or presence of 100  $\mu\text{g/ml}$  or 200  $\mu\text{g/ml}$  black cohosh. (B) Reciprocal plots of the binding data of  $[^3\text{H}]\text{DAMGO}$  to hMOR. ( $\circ$ ) no black cohosh; ( $\bullet$ ) 100  $\mu\text{g/ml}$  black cohosh; ( $\blacksquare$ ) 200  $\mu\text{g/ml}$  black cohosh. Each point represents the mean  $\pm$  SD (N = 3).



**Figure 4.**

A scheme illustrating the mixed competitive action of black cohosh (I) on the binding of DAMGO to the human  $\mu$  opiate receptor (hMOR).  $K_d$ ,  $K_d'$ ,  $K_i$  and  $K_i'$  are dissociation rate constants.



**Figure 5.** Stimulation of  $[^{35}\text{S}]\text{GTP}\gamma\text{S}$  binding by a clinically used 75% ethanol extract of black cohosh (CR-ethanol). CR-ethanol stimulated  $[^{35}\text{S}]\text{GTP}\gamma\text{S}$  binding by  $166 \pm 15\%$ . Each point represents the mean  $\pm$  SD ( $N = 3$ ). The  $\text{EC}_{50}$  value was estimated to be  $78.1 \pm 18.8 \mu\text{g/ml}$ .

**Table 1**

[<sup>3</sup>H]DAMGO binding to the human  $\mu$  opiate receptor in the absence or presence of black cohosh 75% ethanol extract

	black cohosh ( $\mu\text{g/ml}$ )		
	0	100	200
$K_d$ (nM)	0.73	1.62	3.94
$B_{\text{max}}$ (fmol/mg protein)	451.4	267.2	146.5