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Research Article

Specific receptors for leukotriene C4 (LTC4) have been identified on an intact smooth muscle cell line, DDT1 MF-2 cells derived from the Syrian hamster vas deferens. Specific [3H]LTC4 binding at a fixed input at 4 degrees C was rapid, reached a plateau at 86% of total binding at 60 min, and was reversible upon addition of excess homoligand. With incremental inputs of radioligand and a constant cell number, specific [3H]LTC4 binding reached a plateau indicative of saturable binding sites. LIGAND analysis of the Scatchard plot demonstrated a single high affinity binding site with a dissociation constant (Kd) of 5 nM. With incremental inputs of unlabeled LTC4, LIGAND analysis of the Scatchard plot demonstrated a single high affinity site with a Kd of 4.4 nM and in some experiments an additional low affinity site with a Kd of 634 nM. The myotonically active structural analogues of LTC4, 5(R),6(S)-LTC4, 11-trans-LTC4, and C1-monoamide-LTC4, competed effectively with radiolabeled LTC4 such that the relative Kd values of these heteroligands were within one log of that of the homoligand. In contrast, the other native sulfidopeptide leukotrienes, leukotriene D4 and leukotriene E4, exhibited relative Kd values that were 2-3 logs less than that of LTC4. Thus, the high affinity receptor on the DDT1 smooth muscle cell line is specific for a single constituent, LTC4, of slow reacting […]

Specific Receptors for Leukotriene C_4 on a Smooth Muscle Cell Line

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ABSTRACT Specific receptors for leukotriene C_4 (LTC_4) have been identified on an intact smooth muscle cell line, DDT_1 MF-2 cells derived from the Syrian hamster vas deferens. Specific [^{3}H]LTC_4 binding at a fixed input at 4°C was rapid, reached a plateau at 86% of total binding at 60 min, and was reversible upon addition of excess homoligand. With incremental inputs of radioligand and a constant cell number, specific [^{3}H]LTC_4 binding reached a plateau indicative of saturable binding sites. LIGAND analysis of the Scatchard plot demonstrated a single high affinity binding site with a dissociation constant (K_d) of 5 nM. With incremental inputs of unlabeled LTC_4, LIGAND analysis of the Scatchard plot demonstrated a single high affinity site with a K_d of 4.4 nM and in some experiments an additional low affinity site with a K_d of 634 nM. The myotonically active structural analogues of LTC_4, 5(*R*),6(*S*)-LTC_4, 11-*trans*-LTC_4, and C_1-monoamide-LTC_4, competed effectively with radiolabeled LTC_4 such that the relative K_d values of these heteroligands were within one log of that of the homoligand. In contrast, the other native sulfidopeptide leukotrienes, leukotriene D_4 and leukotriene E_4, exhibited relative K_d values that were 2–3 logs less than that of LTC_4. Thus, the high affinity receptor on the DDT_1 smooth muscle cell line is specific for a single constituent, LTC_4, of slow reacting substance of anaphylaxis.

INTRODUCTION

The C-6 sulfidopeptide leukotriene, 5(*S*)-hydroxy-6(*R*)-S-glutathionyl-7,9-*trans*-11,14-*cis*-eicosatetraenoic acid (LTC_4),[1] a product of the oxidation of arachidonic acid by the 5-lipoxygenase pathway, undergoes proteolytic cleavage to 5(*S*)-hydroxy-6(*R*)-S-cysteinyl-glycyl-7,9-*trans*-11,14-*cis*-eicosatetraenoic acid (LTD_4) and 5(*S*)-hydroxy-6(*R*)-S-cysteinyl-7,9-*trans*-11,14-*cis*-eicosatetraenoic acid (LTE_4); and these leukotrienes together constitute the biological activity ascribed to slow-reacting substance of anaphylaxis (1–4). The structural determinants of LTC_4 and LTD_4 function include the presence of a hydrophobic omega region (5), and the geometrical relationships between the eicosanoid carboxyl and the appendages at C-5 and C-6, suggesting the existence of true receptors for this class of agonist (6). In the present study, the saturable and reversible binding of [^{3}H]LTC_4 to intact smooth muscle cells from the hamster vas deferens DDT_1 cell line (7) provides evidence for a receptor for LTC_4; and competition analyses indicate that it is distinct from the putative receptors for LTD_4 and LTE_4.

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[1] *Abbreviations used in this paper:* LTC_4, 5(*S*)-hydroxy-6(*R*)-S-glutathionyl-7,9-*trans*-11,14-*cis*-eicosatetraenoic acid; LTD_4, 5(*S*)-hydroxy-6(*R*)-S-cysteinyl-glycyl-7,9-*trans*-11,14-*cis*-eicosatetraenoic acid; LTE_4, 5(*S*)-hydroxy-6(*R*)-S-cysteinyl-7,9-*trans*-11,14-*cis*-eicosatetraenoic acid.

METHODS

Materials. LTC_4, LTD_4, LTE_4 and the structural leukotriene analogues of LTC_4—5(*R*),6(*S*)-LTC_4, C_1-monoamide-LTC_4, deamino-LTC_4, and 11-*trans*-LTC_4—were prepared as described (4, 6, 8, 9) and stored under argon in 0.05 M phosphate buffer, pH 6.8, containing 20% ethanol at −70°C. [14,15-^{3}H]LTC_4 (40 Ci/mmol, lot 1796-297, and 42.8 Ci/mmol, lot 1917-088) was supplied by New England Nuclear, Boston, MA. FPL 55712 was supplied by Fisons, Ltd., Loughborough, United Kingdom.

Receptor-binding assay. The hamster vas deferens DDT_1 MF-2 cells were provided by Dr. J. S. Norris (University of Arkansas, Little Rock, AR) and were grown in monolayer cultures in 250-ml culture flasks in Dulbecco's modified Eagle's medium containing 4.5 g of glucose/liter, 1% penicillin-streptomycin, and 10% fetal calf serum (7). Monolayer cultures of DDT_1 MF-2 cells were harvested with a rubber policeman; washed twice with Tris-saline, pH 7.4, containing 140 mM NaCl, 5.4 mM KCl, 2.5 mM $CaCl_2$, 1.2 mM $MgCl_2$, 11.2 mM D-glucose, and 10 mM Tris-hydroxy methylaminomethane; and sedimented at 500 *g* for 10 min at room temperature and resuspended in Tris-HCl, pH 7.3. Cell number was determined with a hemocytometer.

Smooth muscle cells (0.5–1 × 10^6) in 0.5 ml Tris-HCl, pH 7.3, containing 1 mM serine-borate complex and 1 mM $CaCl_2$, were combined in 3.5-ml polypropylene tubes with varying concentrations (0.4–13.7 nM) of [^{3}H]LTC_4 for saturation experiments and with fixed amounts of [^{3}H]LTC_4 ranging from 0.4 to 1.5 nM and varying amounts of cold ligands at 4°C for competition experiments. Incubations were routinely continued for 60 min at 4°C and the contents of each tube were filtered under vacuum through separate glass fiber filters (Boehringer Mannheim Biochemicals, Indianapolis, IN) on a Hoeffer filtration manifold (Hoefer Scientific Instruments, San Francisco, CA). Each filter was washed five times with 2-ml portions of cold Tris-HCl buffer, pH 7.3, containing 1 mM serine-borate complex, and then placed in a scintillation vial containing 1 ml of ethanol/water, 4:1 (vol/vol) solution overnight at 25°C. 5 ml of Aquasol (New England Nuclear) was added, and the mixtures were incubated for an additional 4–6 h at 25°C before radioactivity was determined in a scintillation counter (Mark II, Tracor Analytic, Inc., Elk Grove, IL). Total and nonspecific binding of [^{3}H]LTC_4 were determined as the mean of triplicate assays carried out in the absence and in the presence of 3.2 μM unlabeled LTC_4. Specific binding was calculated as the difference between total and nonspecific binding at each concentration of [^{3}H]LTC_4. Binding data were analyzed by the LIGAND computer program (10).

RESULTS

Binding of [^{3}H]LTC_4 to the DDT_1 smooth muscle cells. The total and specific binding of [^{3}H]LTC_4 to 0.3 × 10^6 DDT_1 smooth muscle cells at 4°C increased rapidly over the first 10 min of interaction, progressed slowly to equilibrium at 60 min, and remained stable for up to 120 min. In three experiments, specific binding acounted for 86±8.0% (mean±SD) of the total binding at 60 min (Fig. 1 *a*). Nonspecific binding was maximal at the earliest time point assessed and thereafter was independent of time.

Dissociation of the specifically bound [^{3}H]LTC_4 was

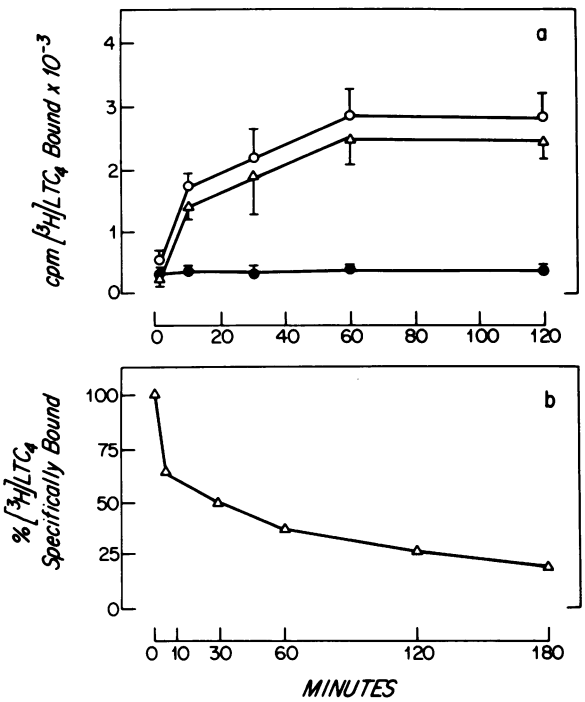

FIGURE 1 (*a*) Time course of total binding (○), nonspecific binding (●), and specific binding (△) of [^{3}H]LTC_4 to DDT_1 cells. Each point represents the mean±SD of three different experiments, each performed in triplicate and using 1.2–1.5 nM [^{3}H]LTC_4. (*b*) Reversibility of specific [^{3}H]LTC_4 binding to the DDT_1 cells after a 60-min incubation at 4°C, by addition of an excess of unlabeled LTC_4 (3.2 μM) and continued incubation at 4°C. The points represent the mean binding of two experiments, each performed in duplicate, expressed as a percent of specific residual binding.

assessed in two experiments by the addition of 3.2 μM unlabeled LTC_4 to replicate tubes containing 0.5 × 10^6 smooth muscle cells that had previously been incubated with 1.5 and 1.2 nM [^{3}H]LTC_4 for 60 min at 4°C; the quantity of [^{3}H]LTC_4 remaining specifically bound was evaluated at subsequent time intervals up to 180 min (Fig. 1 *b*). Dissociation of [^{3}H]LTC_4 occurred with an initial rapid fall at 5 min followed by a slower dissociation to 78% reversibility at 180 min.

Incubation of increasing numbers of the smooth muscle cells from 0.25 to 3.5 × 10^6 and a constant concentration of radioligand (1.5 nM) revealed that specific [^{3}H]LTC_4 binding was incremental over the entire range of cell numbers and was linear for up to 1 × 10^6.

With increasing concentrations of radioligand and 10^6 smooth muscle cells, specific binding of [^{3}H]LTC_4 increased to 0.24 pmol/10^6 cells at concentrations of 6.5 nM [^{3}H]LTC_4 or higher, indicating saturability of specific receptors (Fig. 2). Nonspecific binding increased progressively up to the maximum input as-

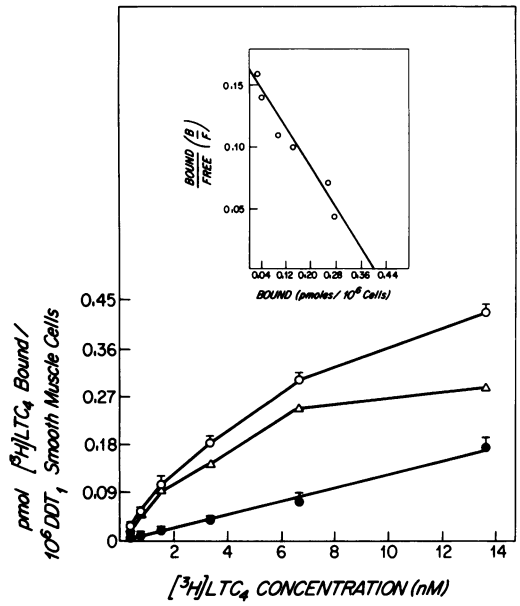

FIGURE 2 Total binding (O), nonspecific binding (●), and specific binding (Δ) of [^{3}H]LTC$_4$ as a function of incremental inputs of [^{3}H]LTC$_4$. Each point represents the mean±SD of triplicate determinations. (*Inset*) Scatchard analysis of binding of [^{3}H]LTC$_4$ to DDT$_1$ smooth muscle cells analyzed with LIGAND (10).

sessed. A Scatchard plot of the data analyzed by the LIGAND computer program (10), described one class of binding sites with a dissociation constant (K_d) of 5 nM and specific binding of 0.4 pmol/10^6 cells (Fig. 2, inset). In a comparable experiment, one class of binding sites was described with a K_d of 5.1 nM and a specific binding of 0.28 pmol/10^6 cells.

To evaluate the specificity of the [^{3}H]LTC$_4$ binding sites, sulfidopeptide leukotrienes, structural analogues of LTC$_4$, and FPL 55712 were assessed for the capacity to inhibit the specific binding of [^{3}H]LTC$_4$. LTC$_4$ at concentrations from 32 pM to 3.2 μM reduced [^{3}H]LTC$_4$ binding in a dose-dependent manner, giving dissociation constants of 4.4±6.2 nM (mean±SD, n = 7) for a high affinity site and a specific binding of 0.59±0.5 pmol/10^6 cells. In four competition studies, a low affinity site with a K_d of 634±871 nM (mean±SD) and a specific binding of 5.15±1.54 pmol/10^6 cells (mean±SD) was also recognized. The abilities of 5(*R*),6(*S*)-LTC$_4$ (relative K_d = 11 nM), 11-*trans*-LTC$_4$ (relative K_d = 10.9 nM), and C$_1$-monoamide-LTC$_4$ (relative K_d = 12.5 nM) to inhibit the binding of [^{3}H]LTC$_4$ were approximately equal and were two- to threefold less potent than LTC$_4$ (Fig. 3). LTD$_4$ (relative K_d = 2.0 μM), LTE$_4$ (relative K_d > 10 μM), deamino-LTC$_4$ (relative K_d > 10 μM) and FPL 55712 (relative K_d = 7.65 μM) were minimally active.

DISCUSSION

The characteristics of [^{3}H]LTC$_4$ binding to intact DDT$_1$ smooth muscle cells satisfy the criteria for a true receptor (11). Specific [^{3}H]LTC$_4$ binding to intact DDT$_1$ smooth muscle cells at 4°C was rapid over the first 10 min of incubation, reached a plateau at 60 min for 86% of the total binding (Fig. 1 *a*), and was reversible by the homologous unlabeled ligand to ~80% of the specifically bound radioligand (Fig. 1 *b*). Specific binding of a fixed input of [^{3}H]LTC$_4$ was a linear function of DDT$_1$ smooth muscle cell numbers and accounted for 90±3% of total binding at each cell num-

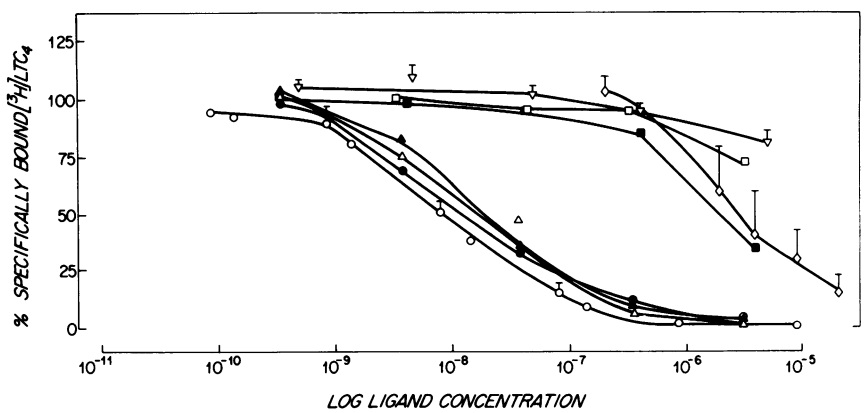

FIGURE 3 Percent inhibition of specific [^{3}H]LTC$_4$ binding by incremental concentrations of LTC$_4$ (O), 5(*R*),6(*S*)-LTC$_4$ (●), 11-*trans*-LTC$_4$ (Δ), C$_1$-monoamide LTC$_4$ (▲), deamino-LTC$_4$ (□), LTD$_4$ (■), LTE$_4$ (▽), and FPL 55712 (◇). Data are presented as the mean at each point ±SD when there were three or more separate experiments.

ber, as would be expected under equilibrium conditions. For a fixed number of DDT_1 cells and incremental concentrations of radioligand, the number of binding sites was saturable and indicated a single binding site with a K_d of 5 nM (Fig. 2) and 5.1 nM in two experiments. Analysis of the competition between a single concentration of [^{3}H]LTC_4 and incremental concentrations of unlabeled LTC_4 with a fixed number of DDT_1 cells (Fig. 3) revealed a high affinity binding site in seven experiments with a K_d of 4.4±6.2 nM. A low affinity receptor with a K_d of 634 nM was also detected in four analyses. The inconsistent ability to demonstrate a low affinity site may reflect dissociation of radioligand from this site during the filtration washing procedure (12).

The [^{3}H]LTC_4 binding sites on the DDT_1 smooth muscle cells are not considered to represent γ-glutamyl transpeptidase because binding was performed in the presence of 1 mM serine-borate complex, a transition state inhibitor of γ-glutamyl transpeptidase (13). In addition, the K_d values of the binding sites for [^{3}H]LTC_4 are 4.4 and 634 nM, as compared with a Michaelis constant (K_m) of ~5.6 μM for kidney γ-glutamyl transpeptidase (14).

Myotonically active analogues of LTC_4, 11-*trans*-LTC_4 and C_1-monoamide-LTC_4, which are, respectively, 71 (4) and 40% (15) as potent as LTC_4 on the guinea pig ileum, displaced specifically bound [^{3}H]LTC_4 from the DDT_1 smooth muscle cells with relative K_d values of 34 and 40% of that of LTC_4. In contrast, deamino-LTC_4, which has 1.7% of the LTC_4 agonist activity (Lewis, R. A., S. Krilis, J. M. Drazen, E. J. Corey, and K. F. Austen, unpublished observations), has a K_d value of <1% of LTC_4 (Fig. 3).

The other myotonically active natural leukotrienes displaced specifically bound [^{3}H]LTC_4 weakly with the relative K_d being 2.0 μM for LTD_4 and >10 μM for LTE_4. The putative leukotriene receptor antagonist, FPL 55712, demonstrated dose-dependent inhibition of binding of [^{3}H]LTC_4 to the DDT_1 smooth muscle cell line with a relative K_d of only 7.65 μM, indicating that it is not a potent, selective receptor antagonist for LTC_4 in this cell line. Thus, the receptor on this nonvascular smooth muscle cell line is highly specific for LTC_4 and cannot be considered to be a class receptor for the sulfidopeptide leukotrienes.

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