A VLA-4 INHIBITOR: OMEPUPA-V

L’OMEPUPA-V, NOUVEL INHIBITEUR DU VLA-4

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Remarks:
The file contains technical information submitted after the application was filed and not included in this specification.

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[0001] The present invention relates to compounds that are useful for inhibition, alteration, or prevention of cell adhesion and cell adhesion-mediated pathologies. This invention also relates to pharmaceutical formulations comprising these compounds, and to the use of these compounds for the preparation of a medicament for inhibition and prevention of cell adhesion and cell adhesion-mediated pathologies. The compounds and pharmaceutical compositions of this invention can be used as therapeutic or prophylactic agents. They are particularly well suited for the treatment of many inflammatory and autoimmune diseases.

[0002] Cell adhesion is a process by which cells associate with each other, migrate towards a specific target or localize within the extra-cellular matrix. As such, cell adhesion constitutes one of the fundamental mechanisms underlying numerous biological phenomena. For example, cell adhesion is responsible for the adhesion of hematopoietic cells to endothelial cells and the subsequent migration of those hematopoietic cells out of blood vessels and to the site of injury. As such, cell adhesion plays a role in numerous pathologies such as, for example, inflammation and immune reactions in mammals.

[0003] Investigations into the molecular basis for cell adhesion have revealed that various cell-surface macromolecules -- collectively known as cell adhesion molecules or receptors -- mediate cell-cell and cell-matrix interactions. For example, proteins of the superfamily called “integrins” are key mediators in adhesive interactions between hematopoietic cells and their microenvironment (M.E. Hemler, “VLA Proteins in the Integrin Family: Structures, Functions, and Their Role on Leukocytes.” Ann. Rev. Immunol., 8, p. 365 (1990)). Integrins are non-covalent heterodimeric complexes consisting of two subunits called α and β. There are at least 17 different α subunits (α1-α10, α-L, α-M, α-D, α-X, α-IIB, α-V and α-E) and at least 9 different β (β1-β9) subunits which have been identified to date. Based on the type of its α and β subunit components, each integrin molecule can be categorized into a subfamily.


[0005] In order to identify the minimum active amino acid sequence necessary to bind VLA-4, Komoriya et al. synthesized a variety of overlapping peptides based on the amino acid sequence of the CS-1 region (the VLA-4 binding domain) of a particular species of fibronectin. (“The Minimal Essential Sequence for a Major Cell Type-Specific Adhesion Site (CS1) Within the Alternatively Spliced Type III Connecting Segment Domain of Fibronectin Is Leucine-Aspartic Acid-Valine”, J. Biol. Chem., 266 (23), pp. 15075-79 (1991)). They identified an 8-amino acid peptide, Glu-Ile-Leu-Asp-Val-Pro-Ser-Thr, as well as two smaller overlapping pentapeptides, Glu-Ile-Leu-Asp-Val and Leu-Asp-Val-Pro-Ser, that possessed inhibitory activity against FN-dependent cell adhesion. These results suggested that the tripeptide Leu-Asp-Val was the minimum sequence for cell-adhesion activity. It was later shown that Leu-Asp-Val binds only to lymphocytes that express an activated form of VLA-4, thus casting doubt on the utility of such a peptide in vivo (E.A. Wayner et al., “Activation-Dependent Recognition by Hematopoietic Cells of the LDV Sequence in the V Region of Fibronectin”, J. Cell. Biol., 116(2), pp. 489-497 (1992)). However, certain larger peptides containing the LDV sequence were subsequently shown to be active in vivo (T. A. Ferguson et al., “Two Integrin Binding Peptides Abrogate T-cell-Mediated Immune Responses In Vivo”, Proc. Natl. Acad. Sci. USA; 88, pp. 8072-76 (1991); and S. M. Wahl et al., “Synthetic Fibronectin Peptides Suppress Arthritis in Rats by Interrupting Leukocyte Adhesion and Recruitment”, J. Clin. Invest., 94, pp. 655-62 (1994)). A cyclic pentapeptide which can inhibit both VLA-4 and VLA-5 adhesion to FN has also been described. (See, e.g., D.M. Nowlin et al. “A Novel Cyclic Pentapeptide Inhibits α4β1 and α5β1 Integrin-mediated Cell Adhesion”, J. Biol. Chem., 268(27), pp. 20352-59 (1993); and PCT publication PCT/US91/04862). This pentapeptide was based on the tripeptide sequence Arg-Gly-Asp from FN which had been known as a common motif in the recognition site for several extracellular-matrix proteins.

[0006] Examples of other VLA-4 inhibitors have been reported, for example, in copending United States patent application 08/376,372, and WO98/04913 specifically incorporated by reference herein. USSN 376,372 describes linear peptidyl compounds containing β-amino acids which have cell adhesion inhibitory activity. International patent applications WO 94/15958 and WO 92/00995, specifically incorporated by reference, describe cyclic peptide and peptid...
mimetic compounds with cell adhesion modulating activity. International patent applications WO 93/08823 and WO 92/08464 (specifically incorporated by reference herein) describe guanidinyl-, urea- and thiourea-containing cell adhesion modulating compounds. United States Patent No. 5,260,277 describes guanidinyl cell adhesion modulation compounds, and is also specifically incorporated herein.

Despite these advances, there remains a need for low molecular weight, specific inhibitors of VLA-4 dependent cell adhesion that have improved pharmacokinetic and pharmacodynamic properties such as oral bioavailability and significant duration of action. Such compounds would provide useful agents for treatment, alteration, prevention or suppression of various pathologies mediated by cell adhesion and VLA-4 binding.

SUMMARY OF THE INVENTION

The compounds of the present invention are inhibitors of the VLA-4 integrin, thereby blocking the binding of VLA-4 to its various ligands, such as VCAM-1 and regions of fibronectin. Thus these compounds are useful in inhibiting cell adhesion processes including cell activation, migration, proliferation and differentiation. These compounds are useful for inhibition, prevention and suppression of VLA-4-mediated cell adhesion and pathologies associated with that adhesion, such as inflammation and immune reactions, including for example, multiple sclerosis, asthma, allergic rhinitis, allergic conjunctivitis, inflammatory lung diseases, rheumatoid arthritis, septic arthritis, type 1 diabetes, organ transplantation, restenosis, autologous bone marrow transplantation, inflammatory sequelae of viral infections, myocarditis, inflammatory bowel disease including ulcerative colitis and Crohn’s disease, certain types of toxic and immune-based nephritis, contact dermal hypersensitivity, psoriasis, tumor metastasis, multiple myeloma, and atherosclerosis. The compounds of this invention may be used alone or in combination with other therapeutic or prophylactic agents to inhibit, alter, prevent or suppress cell adhesion. This invention also provides pharmaceutical formulations containing these VLA-4-mediated cell adhesion inhibitors and the use of the compounds and compositions of the invention for the preparation of a medicament for inhibition of cell adhesion.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 reports the airway responsiveness of sheep after treatment with oMePUPA-V. Sheep, naturally sensitive to Ascaris suum, were challenged with an aerosol of Ascaris suum allergen 2 h after aerosol administration of oMePUPA-V at the indicated doses or an equivalent amount of vehicle. Pulmonary mechanics were measured at the indicated times and are reported as the change in specific airways resistance from the pre-study baseline value (left panels). Airways resistance to inhaled carbachol was determined prior to study initiation and at 24 h post-allergen challenge (right panels). Airways responsiveness is reported as the PC400 (amount of carbachol required to increase resistance by 400%) ratio by comparison of pre-challenge and post-challenge values.

Figure 2: Sheep, naturally sensitive to Ascaris suum, were challenged with an aerosol administration of oMePUPA-V at the doses indicated or an aerosol of Ascaris suum. Changes in airways resistance were measured following aerosol challenge and peak specific lung resistance (cm H2O/sec) after challenge was compared to baseline values. *=p<0.05 compared to PBS control, one-way analysis of variance, followed by Dunnett’s test for multiple comparison to a control group. Indicates a statistically significant increase in peak specific lung resistance compared to PBS control group.

Figure 3: Sheep, naturally sensitive to Ascaris suum, were challenged with an aerosol of Ascaris suum allergen 24 h after the fourth daily aerosol administration of oMePUPA-V (0.03 mg) or an equivalent amount of vehicle (ethanol:normal saline, 1:2, upper panel; Tris:normal saline, 1:499, lower panel). Pulmonary mechanics were measured at the indicated times and are reported as the change in specific airways resistance from the pre-study baseline value (left panels). Airways resistance to inhaled carbachol was determined prior to study initiation and at 24 h post-allergen challenge (right panels). Airways responsiveness is reported as the PC400 (amount of carbachol required to increase resistance by 400%) ratio by comparison of pre-challenge and post-challenge values.

Figure 4: Balb/c mice, previously sensitized to DNFB, were challenged by application of DNFB to the dorsal surface of the left ear and vehicle to the dorsal surface of the right ear. Twenty-four hours later the thickness of the ears was measured with a micrometer. oMePUPA-V was administered at the indicated doses 4 hours after challenge with DNFB. Positive control (+CTRL) compound was given at a maximally effective enteral dose. Values are means ± standard error of the mean for 8 animals. Upper panel shows absolute ear swelling. Lower panel shows percent inhibition of ear swelling compared to vehicle (VEH) control.

Figure 5: LIBS induction by α4β1 antagonists was assayed in vitro by FACS analysis. Jurkat cells (2 x 10^5/well) were preincubated at 37°C for 20 minutes with TRIS-buffered saline containing 2mM MgCl2 (Mg²⁺,TBS) alone or with serial dilutions of test compounds. The samples were transferred to an ice bath and supplemented with LIBS
antibody, 9EG7, at a final concentration of 10 µg/ml. The cells were washed twice with Mg\textsuperscript{2+}-TBS and resuspended in a 1:200 dilution of a FITC conjugated-goat anti-rat IgG in Mg\textsuperscript{2+}-TBS. Mean fluorescence intensity (MFI) was determined by FACS analysis (Becton Dickinson FACScan). Upper panel shows LIBS induction by oMePUPA-V with 1mM Mn\textsuperscript{2+} buffer. Lower panel shows LIBS induction by oMePUPA-V compared to 2mM Mg\textsuperscript{2+} buffer.

DETAILED DESCRIPTION

[0010] The present invention provides compounds, which are capable of inhibiting VLA-4 mediated cell adhesion by inhibiting the binding of ligands to that receptor. The preferred compound is (R)-N-[4-[[2-(methylphenylamino) carbonyl] amino]phenyl]acetyl]-L-prolyl-3-methyl)-β-Alanine, referred to herein as "oMePUPA-V", represented by the following formula I:

![Chemical Structure]

and is referred to herein as "oMePUPA-V". The invention is also intended to encompass pharmaceutically acceptable derivatives, salts, and esters of oMePUPA-V.

[0011] Compounds of Formula I contain one or more asymmetric centers and thus can occur as racemic mixtures, single enantiomers, diastereomeric mixtures and individual diastereomers. The present invention is meant to comprehend all such isomeric forms of the compound of Formula I.

[0012] The claimed invention is also intended to encompass pharmaceutically acceptable salts of Formula I. The term "pharmaceutically acceptable salts" refers to salts prepared from pharmaceutically acceptable non-toxic bases or acids including inorganic or organic bases and inorganic or organic acids. Salts derived from inorganic bases include aluminum, ammonium, calcium, copper, ferric, ferrous, lithium, magnesium, manganese salts, manganous, potassium, sodium, zinc, and the like. Particularly preferred are the ammonium, calcium, magnesium, potassium and sodium salts.

[0013] Salts derived from pharmaceutically acceptable organic non-toxic bases include salts of primary, secondary, and tertiary amines, substituted amines including naturally occurring substituted amines, cyclic amines, and basic ion exchange resins, such as arginine, betaine, caffeine, choline, N,N'-dibenzylethylenediamine, diethylamine, 2-diethylaminoethanol, 2-dimethylaminoethanol, ethanolamine, ethylenediamine, N-ethylmorpholine, N-ethylpiperidine, glucamime, glucosamine, histidine, hydrazine, isopropylamine, lysine, methylglucamine, morpholine, piperazine, piperidine, polyamine resins, procaine, purines, theobromine, triethylamine, trimethylamine, tripiperydine, tromethamine, and the like.

[0014] When the compound of the present invention is basic, salts may be prepared from pharmaceutically acceptable non-toxic acids, including inorganic and organic acids. Such acids include acetic, benzenesulfonic, benzoic, camphorsulfonic, citric, ethanesulfonic, fumaric, gluconic, glutamic, hydrobromic, hydrochloric, isethionic, lactic, maleic, malic, mandelic, methanesulfonic, mucic, nitric, pamoic, pantethenic, phosphoric, succinic, sulfuric, tartric, p-toluene sulfonic acid, and the like. Particularly preferred are citric, hydrobromic, hydrochloric, maleic, phosphoric, sulfuric and tartaric acids.

[0015] Additionally, the claimed invention encompasses ester prodrugs wherein the carboxyl group of:

(R)-N-[4-[[2-(methylphenylamino)carbonyl]amino]phenyl]acetyl]-L-prolyl-3-methyl)-β-Alanine is esterified with any of the alcohols. Preferred alcohols are methanol, ethanol, propanol, butanol, or straight or branched chain alkyl C\textsubscript{1-10} alcohols.

[0016] The ability of the compounds of Formula I to antagonize the actions of VIA-4 makes them useful for preventing, treating, or reversing the symptoms, disorders or diseases induced by the binding of VLA-4 to its ligands. Thus these antagonists will inhibit cell adhesion processes including cell activation, migration, proliferation and differentiation. Accordingly, another aspect of the present invention provides the use of these compounds for the preparation of a medicament for the treatment, prevention, alleviation, or suppression of diseases or disorders mediated by the VLA-4 pathway. Such diseases and disorders include, for example, asthma, multiple sclerosis, allergic rhinitis, allergic conjunctivitis, inflammatory lung diseases, rheumatoid arthritis, multiple myeloma, septic arthritis, type I diabetes, organ
transplant rejection, inflammatory bowel disease, and others.

[0017] Compounds of this invention may be synthesized using any conventional technique, several of which are exemplified herein. Preferably, these compounds are chemically synthesized from readily available starting materials, such as α-amino acids and their functional equivalents. Modular and convergent methods for the synthesis of these compounds are also preferred. In a convergent approach, for example, large sections of the final product are brought together in the last stages of the synthesis, rather than by incremental addition of small pieces to a growing molecular chain.

[0018] As used throughout this application, the term "patient" refers to mammals, including humans. And the term "cell" refers to any cell, preferably mammalian cells, including human cells.

[0019] Once synthesized, the activities and VLA-4 specificities of the compounds according to this invention may be determined using in vitro and in vivo assays.

[0020] For example, the cell adhesion inhibitory activity of these compounds may be measured by determining the concentration of inhibitor required to block the binding of VLA-4-expressing cells to fibronectin- or CS1-coated plates. In this type of assay, microtiter wells are coated with either fibronectin (containing the CS-1 sequence) or CS-1. If CS-1 is used, it must be conjugated to a carrier protein, such as bovine serum albumin, in order to bind to the wells. Once the wells are coated, varying concentrations of the test compound are then added together with appropriately labeled VLA-4-expressing cells. Alternatively, the test compound may be added first and allowed to incubate with the coated wells prior to the addition of the cells. The cells are allowed to incubate in the wells for at least 30 minutes. Following incubation, the wells are emptied and washed. Inhibition of binding is measured by quantitating the fluorescence or radioactivity bound to the plate for each of the various concentrations of test compound, as well as for controls containing no test compound.

[0021] VLA-4-expressing cells that may be utilized in this assay include Ramos cells, Jurkat cells, A375 melanoma cells, as well as human peripheral blood lymphocytes (PBLs). The cells used in this assay may be labeled in any appropriate manner, for example fluorescently or radioactively labeled.

[0022] A direct binding assay may also be employed to quantitate the inhibitory activity of the compounds of this invention. In this assay, a VCAM-IgG fusion protein containing the first two immunoglobulin domains of VCAM (D1D2) attached above the hinge region of an IgG 1 molecule ("VCAM 2D-IgG"), is conjugated to a marker enzyme, such as alkaline phosphatase ("AP"). The synthesis of this VCAM-IgG fusion is described in PCT publication WO 90/13300, the disclosure of which is herein incorporated by reference. The conjugation of that fusion to a marker enzyme is achieved by cross-linking methods well-known in the art.

[0023] The VCAM-IgG enzyme conjugate is then placed in the wells of a multi-well filtration plate, such as that contained in the Millipore Multiscreen Assay System (Millipore Corp., Bedford, MA). Varying concentrations of the test inhibitory compound are then added to the wells followed by addition of VLA-4-expressing cells. The cells, compound and VCAM-IgG enzyme conjugate are mixed together and allowed to incubate at room temperature.

[0024] Following incubation, the wells are vacuum drained, leaving behind the cells and any bound VCAM. Quantitation of bound VCAM is determined by adding an appropriate colorimetric substrate for the enzyme conjugated to VCAM-IgG and determining the amount of reaction product. Decreased reaction product indicates increased binding activity. The protocol for certain assays is described below:

[0025] In order to assess the VLA-4 inhibitory specificity of the compounds of this invention, assays for other major groups of integrins, i.e., β2 and β3, as well as other β1 integrins, such as VLA-5, VLA-6 and α4β7 are performed. These assays may be similar to the adhesion inhibition and direct binding assays described above, substituting the appropriate integrin-expressing cell and corresponding ligand. For example, polymorphonuclear cells (PMNs) express β2 integrins on their surface and bind to ICAM. β3 integrins are involved in platelet aggregation and inhibition may be measured in a standard platelet aggregation assay. VLA-5 binds specifically to Arg-Gly-Asp sequences, while VLA-6 binds to laminin. α4β7 is a recently discovered homologue of VLA-4, which also binds fibronectin and VCAM. Specificity with respect to α4β7 is determined in a binding assay that utilizes the above-described VCAM-IgG-enzyme marker conjugate and a cell line that expresses α4β7, but not VLA-4, such as RPMI-8866 or JY cells.

[0026] Once VLA-4-specific inhibitors are identified, they may be further characterized in vivo assays. One such assay tests the inhibition of contact hypersensitivity in an animal, such as described by P.L. Chisholm et al., "Monoclonal Antibodies to the Integrin α-4, Subunit Inhibit the Murine Contact Hypersensitivity Response", Eur. J. Immunol., 23, pp. 682-688 (1993) and in "Current Protocols in Immunology", J. E. Coligan, et al., Eds., John Wiley & Sons, New York, 1, pp. 4.2.1-4.2.5 (1991), the disclosures of which are herein incorporated by reference. In this assay, the skin of the animal is sensitized by exposure to an irritant, such as dinitrofluorobenzene, followed by light physical irritation, such as scratching the skin lightly with a sharp edge. Following a recovery period, the animals are re-sensitized following the same procedure. Several days after sensitization, one ear of the animal is exposed to the chemical irritant, while the other ear is treated with a non-irritant control solution. Shortly after treating the ears, the animals are given various doses of the VLA-4 inhibitor by subcutaneous injection. In vivo inhibition of cell adhesion-associated inflammation is assessed by measuring the ear swelling response of the animal in the treated versus untreated ear. Swelling is meas-
ured using calipers or other suitable instrument to measure ear thickness. In this manner, one may identify those inhibitors of this invention which are best suited for inhibiting inflammation.

[0027] Another in vivo assay that may be employed to test the inhibitors of this invention is the sheep asthma assay. This assay is performed essentially as described in W. M. Abraham et al., "α4-Integrins Mediate Antigen-induced Late Bronchial Responses and Prolonged Airway Hyperresponsiveness in Sheep", J. Clin. Invest., 93, pp. 776-87 (1994), the disclosure of which is herein incorporated by reference. This assay measures inhibition of Ascaris antigen-induced late phase airway responses and airway hyperresponsiveness in allergic sheep. The compounds of this invention may also be tested in a platelet aggregation assay.

[0028] The VLA-4 inhibitors of the invention have shown surprisingly favorable activity and selectivity. Generally, these compounds are selective for VLA-4 (>1000-fold versus α4β7 and α5β1), negative in routine PanLabs and non-GLP Ames assays; clean in standard ancillary pharmacology tests and effective in the sheep model following once-a-day dosing at a predicted use level in man of 1 mg/day or less.

[0029] The claimed compounds have surprisingly superior potency as compared to structurally related VLA-4 inhibitors. For example, in Ascaris-sensitive sheep treated once daily for four days with nebulized drug at 0.1 mg/kg and then challenged with antigen 24 hours after the last dose, previously tested compounds substantially attenuated the early response and blocked late phase bronchoconstriction and the development of non-specific hyperresponsiveness. Assuming bioequivalence in man, a total dose of 7 mg would be required in a 70 kg person. Furthermore, drug was administered to the sheep through an endotracheal tube at deposition rates estimated to be 2-fold greater than is typically achieved in man with oral inhaler devices. Additionally, it is likely that excipients will need to be added to the final solid formulation to optimize device filling and drug delivery. These factors suggest a possible dose requirement in man of 14 mg or more which exceeds the technical limit of 1-5 mg, that can be delivered in one actuation through a dry powder inhaler (DPI) device. While the necessary dose could be delivered by multiple actuations of the DPI, this would represent a competitive disadvantage in the asthma market where typical inhaled steroid doses are 0.2-1.0 mg.

[0030] oMePUPA-V attenuated the early response, blocked late-phase bronchoconstriction and normalized hyperresponsiveness at a minimum dose of 0.003 mg/kg when administered as a single nebulized dose 2 hours before antigen challenge. Moreover, a daily dose of 0.001 mg/kg for 4 days with antigen challenge 24 hours after the last dose gives a maximum response. Thus, oMePUPA-V is 30 to 100-fold more potent than previous compounds, with dose levels in the range of the best marketed inhaled steroids. oMePUPA-V, as well as the penultimate synthetic intermediate, is highly crystalline. (See Figure 1, Table 1)

[0031] Additionally, oMePUPA-V has an improved metabolic profile as compared to known VLA-4 inhibitors. For example, following aerosol administration, the claimed compounds were rapidly converted to a less active metabolite, which was the predominant product recovered from bronchoalveolar lavage fluid (BALF) and was also the predominant product observed in the systemic circulation where it exhibited a longer plasma half-life than the parent compound. While rapid metabolic conversion to less active compounds is a useful strategy to achieve reduced systemic exposure, compounds which are metabolized to by-products with little or no intrinsic activity present fewer complexities in development and are preferred from a backup perspective.

[0032] The potential proteolytic products of oMePUPA-V are inactive in VLA-4 binding assays so proteolysis would generate inactive products regardless. Nevertheless, in vitro metabolism studies as well as in vivo PK studies in rat, dog and sheep have shown oMePUPA-V to be proteolytically stable.

### Table 1.

Properties of oMePUPA-V Compared to previously known inhibitors.

<table>
<thead>
<tr>
<th>Property</th>
<th>Previous Cmpd</th>
<th>oMePUPA-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC50 against VLA-4-VCAM-Ig binding</td>
<td>1.5 nM</td>
<td>2.7 nM</td>
</tr>
<tr>
<td>IC50 against α4β7-VCAM-Ig binding</td>
<td>2.7 µM</td>
<td>&gt;100 µM</td>
</tr>
<tr>
<td>IC50 against α5β1-FN adhesion</td>
<td>&gt;100 µM</td>
<td>&gt;100 µM</td>
</tr>
<tr>
<td>Minimum effective dose in sheep model</td>
<td>0.1 mg/kg</td>
<td>0.003 mg/kg</td>
</tr>
<tr>
<td>- single dose</td>
<td>0.03-0.1 mg/kg</td>
<td>0.001 mg/kg</td>
</tr>
<tr>
<td>- repeat-dose</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Crystallinity</td>
<td>1 weak hit</td>
<td>clean</td>
</tr>
<tr>
<td>In vitro pharma screen 85 tests</td>
<td>ACE substrate</td>
<td>clean</td>
</tr>
<tr>
<td>ACE activity</td>
<td>low levels</td>
<td>planned</td>
</tr>
<tr>
<td>Glucuronidation</td>
<td>clean</td>
<td>clean</td>
</tr>
<tr>
<td>Ames test (mutagenicity)</td>
<td>clean</td>
<td>clean</td>
</tr>
<tr>
<td>Ancillary pharmacology (side-effects)</td>
<td>clean</td>
<td>clean</td>
</tr>
</tbody>
</table>
TABLE 1. (continued)

<table>
<thead>
<tr>
<th>Property</th>
<th>Previous Cmpd</th>
<th>oMePUPA-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systemic exposure. 10 mg aerosol dose (sheep)</td>
<td>40 ng/ml x hr</td>
<td>finished</td>
</tr>
<tr>
<td>Metabolic profile</td>
<td>active metabolite</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Oral availability</td>
<td>&lt;1%</td>
<td>&quot;unstable&quot;</td>
</tr>
<tr>
<td>Bulk stability (40 °C, 75% RH)</td>
<td>0.2% degradation/day</td>
<td>stable &gt; 4 wk</td>
</tr>
<tr>
<td>Formulated stability (40 °C)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The compounds of the present invention may be formulated into pharmaceutical compositions that may be administered orally, parenterally, by inhalation spray, topically, rectally, nasally, buccally, vaginally or via an implanted reservoir. The term "parenteral" as used herein includes subcutaneous, intravenous, intramuscular, intra-articular, intrasynovial, intraternal, intrathecal, intrahepatic, intrasional and intracranial injection or infusion techniques.

According to this invention, the pharmaceutical compositions may be in the form of a sterile injectable preparation, for example a sterile injectable aqueous or oleaginous suspension. This suspension may be formulated according to techniques known in the art using suitable dispersing or wetting agents and suspending agents. The sterile injectable preparation may also be a sterile injectable solution or suspension in a non-toxic parenterally-acceptable diluent or solvent, for example as a solution in 1,3-butanediol. Among the acceptable vehicles and solvents that may be used are water, Ringer’s solution and isotonic sodium chloride solution. In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium. For this purpose, any bland fixed oil may be employed including synthetic mono- or di-glycerides. Fatty acids, such as oleic acid and its glyceride derivatives are useful in the preparation of injectables, as do natural pharmaceutically-acceptable oils, such as olive oil or castor oil, especially in their polyoxyethylated versions. These oil solutions or suspensions may also contain a long-chain alcohol diluent or dispersant.

The pharmaceutical compositions of this invention may be orally administered in any orally acceptable dosage form including, but not limited to, capsules, tablets, aqueous suspensions or solutions. In the case of tablets for oral use, carriers which are commonly used include lactose and corn starch. Lubricating agents, such as magnesium stearate, are also typically added. For oral administration in a capsule form, useful diluents include lactose and dried corn starch. When aqueous suspensions are required for oral use, the active ingredient is combined with emulsifying and suspending agents. If desired, certain sweetening, flavoring or coloring agents may also be added.

Alternatively, the pharmaceutical compositions of this invention may be administered in the form of suppositories for rectal administration. These may be prepared by mixing the agent with a suitable non-irritating excipient which is solid at room temperature but liquid at the rectal temperature and therefore will melt in the rectum to release the drug. Such materials include cocoa butter, beeswax and polyethylene glycols.

The pharmaceutical compositions of this invention may also be administered topically, especially when the target of treatment includes areas or organs readily accessible by topical application, including, for example, diseases of the eye, the skin, or the lower intestinal tract. Suitable topical formulations are readily prepared for each of these areas or organs.

Topical application for the lower intestinal tract can be effected in a rectal suppository formulation (see above) or in a suitable enema formulation. Topically-transdermal patches may also be used.

For topical applications, the pharmaceutical compositions may be formulated in a suitable ointment containing the active component suspended or dissolved in one or more carriers. Carriers for topical administration of the compounds of this invention include, but are not limited to, mineral oil, liquid petrolatum, white petrolatum, propylene glycol, polyoxyethylene, polyoxypropylene compound, emulsifying wax and water. Alternatively, the pharmaceutical compositions can be formulated in a suitable lotion or cream containing the active components suspended or dissolved in one or more pharmaceutically acceptable carriers. Suitable carriers include, but are not limited to, mineral oil, sorbitan
monostearate, polysorbate 60, cetyl esters wax, cetaryl alcohol, 2-octyldodecanol, benzyl alcohol and water.

**[0041]** For ophthalmic use, the pharmaceutical compositions may be formulated as microaized suspensions in isotonic, pH adjusted sterile saline, or, preferably, as solutions in isotonic, pH adjusted sterile saline, either with or without a preservative such as benzylalkonium chloride. Alternatively, for ophthalmic uses, the pharmaceutical compositions may be formulated in an ointment such as petrolatum.

**[0042]** The pharmaceutical compositions of this invention may also be administered by nasal aerosol or inhalation through the use of a nebulizer, a dry powder inhaler or a metered dose inhaler. Such compositions are prepared according to techniques well-known in the art of pharmaceutical formulation and may be prepared as solutions in saline, employing benzyl alcohol or other suitable preservatives, absorption promoters to enhance bioavailability, fluorocarbons, and/or other conventional solubilizing or dispersing agents. Additionally, the compositions of the invention may include any pharmaceutically acceptable carriers, such as, for example, lactose for dry powder formulations.

**[0043]** The amount of active ingredient that may be combined with the carrier materials to produce a single dosage form will vary depending upon the host treated, and the particular mode of administration. It should be understood, however, that a specific dosage and treatment regimen for any particular patient will depend upon a variety of factors, including the activity of the specific compound employed, the age, body weight, general health, sex, diet, time of administration, rate of excretion, drug combination, and the judgment of the treating physician and the severity of the particular disease being treated. The amount of active ingredient may also depend upon the therapeutic or prophylactic agent, if any, with which the ingredient is co-administered.

**[0044]** The dosage and dose rate of the compounds of this invention effective to prevent, suppress or inhibit cell adhesion will depend on a variety of factors, such as the nature of the inhibitor, the size of the patient, the goal of the treatment, the nature of the pathology to be treated, the specific pharmaceutical composition used, and the judgment of the treating physician. Dosage levels of between about 0.001 and about 100 mg/kg body weight per day, preferably between about 0.01 to about 50 mg/kg and more preferably about 10 mg/kg body weight per day of the active ingredient compound are useful.

**[0045]** For use where a composition for intravenous administration is employed, a suitable dosage range is from about 0.001 mg to about 25 mg/kg, more preferably about 0.01 mg to about 1 mg/kg.

**[0046]** According to another embodiment compositions containing a compound of this invention may also comprise an additional agent selected from the group consisting of corticosteroids, bronchodilators; antiasthmatics (mast cell stabilizers), antiinflammatories, antirheumatics, immunosuppressants, antimetabolites, immunonodulators, antipsoritics and antidiabetics. Specific compounds within each of these classes may be selected from any of those listed under the appropriate group headings in "Comprehensive Medicinal Chemistry", Pergamon Press, Oxford, England, pp. 970-986 (1990), the disclosure of which is herein incorporated by reference. Also included within this group are compounds such as theophylline, sulfasalazine and aminosalicylates (antiinflammatories); cyclosporin, FK-506, and rapamycin (immunosuppressants); cyclophosphamide and methotrexate (antimetabolites); steroids (inhaled, oral or topical) and interferons (immunomodulators). Furthermore, the compounds of the invention may be administered in conjunction with additional cell adhesion inhibitors. When administering one or more additional agents in combination with the claimed VLA-4 inhibitor, the active ingredients may be formulated together, or, alternatively may be administered in combination. Administration of one or more active agents in combination with the VLA-4 inhibitors of the claimed invention may be substantially simultaneous, or sequential. Those skilled in the art can easily determine the most appropriate application depending upon the agents to be delivered, the desired results, and the patient, and condition being treated.

**[0047]** According to other embodiments, the invention provides the use of these compounds for the preparation of a medicament for preventing, inhibiting, or suppressing cell adhesion-associated inflammation and cell adhesion-associated immune or autoimmune responses in a patient. VLA-4-associated cell adhesion plays a central role in a variety of inflammation, immune and autoimmune diseases. Thus, inhibition of cell adhesion by the compounds of this invention may be utilized in methods of treating or preventing inflammatory, immune and autoimmune diseases. Preferably the compounds of the present invention are useful for the treatment of diseases selected from asthma, arthritis, psoriasis, transplantation rejection, multiple sclerosis, diabetes and inflammatory bowel disease.

**[0048]** The compounds of this invention are useful in a monotherapy or in combination with an anti-inflammatory or immunosuppressive agent. Such combination therapies include administration of the agents in a single dosage form or in multiple dosage forms administered at the same time or at different times.

**EXAMPLES**

Example 1. Preparation of oMePUPA-V

**[0049]** oMePUPA-V, (R)-N-[[4-[[2-(methylphenylamino)carbonyl]amino]phenyl]acetyl]-L-prolyl-3-methyl)-β-Alanine, was prepared in a convergent synthesis from commercially manufactured succinimidy Boc-(L)-proline (Boc-Pro-OSu;
Bachem) and (R)-benzyl-3-aminobutyrate hemisulfate (Celgene Corp.). Coupling of the starting materials in CH₂Cl₂ in the presence of Et₃N, followed by hydrolysis of the Boc group with 4 N HCl in dioxane afforded the HCl salt which was recrystallized from CH₂Cl₂/Et₂O. Coupling of the HCl salt with succinimidyl-2-[4-[(2-methylphenylaminocarbonyl)] amino phenyl acetate (MPUPA-OSu), prepared from the corresponding acid, MPUPA-OH (Ricerca, Inc.), provided crystalline oMePUPA-V-benzyl ester which was catalytically hydrogenated (10 % Pd/C) in THF/H₂O (9:1) to provide oMePUPA-V. The final product was obtained as a white solid after recrystallization from 20 % aqueous acetone.

Summary of Physical Characteristics

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>(R)-N-[[4-[[2-methylphenylamino]carbonyl]amino]phenyl] acetyl-L-prolyl-3-methyl]-b-Alanine,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical Formula</td>
<td>C₂₅H₃₀N₄O₅</td>
</tr>
<tr>
<td>Molecular Weight</td>
<td>466.53</td>
</tr>
<tr>
<td>Appearance</td>
<td>Clean white powder</td>
</tr>
<tr>
<td>Melting Point</td>
<td>153.6 - 154.4°C</td>
</tr>
</tbody>
</table>

Scheme 1.

Preparation of MPUPA-OSu (2) from MPUPA-OH (1)
Synthesis of oMePUPA-V (8) from Boc-(L)-Pro-OSu (3) and benzyl-(R)-3-aminobutyrate hemisulfate (4).

[0052]

Scheme 2.

Synthesis of oMePUPA-V

[0053] The synthetic chemistry that was employed to prepare oMePUPA-V is depicted in Schemes 1 and 2. The starting materials were obtained from commercial sources and contract manufacturers: (1) was prepared in large quantity by Ricerca, Inc., Painesville, OH; (3) was obtained from Bachem Bioscience, Inc., King of Prussia, PA and (4) from Celgene Corp., Warren, NJ.

Preparation of oMePUPA-V:

General analytical methods ($^1$H NMR, $^{13}$C NMR, MS, IR & HPLC)

[0054] $^1$H NMR were run either on a Bruker AC 300 or a Varian 500 or a Varian 600 instrument and samples were run either in DMSO-$d_6$ and referenced to DMSO-$d_6$ (d 2.49 ppm) or in CDCl$_3$ and referenced to residual CHCl$_3$ (d 7.24 ppm).

[0055] $^{13}$C NMR were run either on a Varian 500 or a Varian 600 instrument and samples were run either in DMSO-$d_6$ and referenced to DMSO-$d_6$ (d 40.5 ppm) or in CDCl$_3$ and referenced to CDCl$_3$ (d 77.0 ppm).

[0056] Mass Spectra were run on a Fisons VG Platform LC-MS-DS Mass Spectrometer System with a Hewlett Packard Model 1500 AutoSampler and the data processed using a Fisons VG MassLynx Mass Spectrometer Workstation. The HRMS work was run at M-Scan (PA) using Fast Atom Bombardment on a VG Analytical ZAB 2SE high field mass spectrometer with reference to SOP# MS-002, MS-006, MS-012 and MS-023. A cesium ion gun was used to generate ions for the acquired mass spectra which were recorded using a PDP-11-250J data system.

[0057] IR spectra were performed on a Perkin Elmer 1600 Series FTIR.

[0058] Analytical HPLC chromatography was performed as follows:

1. Chromatograms using Program 1 (Equilibrate @ 20% B, inject sample, 20% B (1 min.), 20% - 70% B (24 min.), 70% -100% B (17 min.) were obtained using a Perkin Elmer Series 200 HPLC autosampler system with a Perkin
Elmer 785A UV detector (set at 214 nm) and an Applied Biosystems 783A UV detector (set at 254 nm) with a PE Nelson 1020 integrator. Only the area percent values were reported.

2. Chromatograms using Program 8 (Equilibrate @ 15% B, inject sample, 15% B (1 min.), 15% - 40% B (25 min.), 40% B (10 min.) were obtained using an Applied Biosystems 400 Solvent Delivery System with a 783A wavelength UV detector using a Waters 717 autosampler. The data was processed using a Hewlett Packard 3396 Series II integrator. The integrator was set with the following parameters: Attenuation = 8, Threshold = 5, Area Rejection = 10000, Peak Width = 0.04, Chart Speed = 0.2.

All HPLC work was performed using a Vydac C-18 column (5 m pore size, 4.5 mm x 25 cm, cat. # 218TP54).

Solvent A (water + 0.1 % TFA)
Solvent B (acetonitrile + 0.1 % TFA)
Flow rate = 1 mL/min
The gradient programs are as follows:
Program 1:Equilibrate @ 20% B, inject sample, 20% B (2 min.), 20% - 70% B (25 min.), 100% B (5 min.).

Physical data for [4-[[2-(Methylphenyl)amino]carbonyl]amino]phenyl]acetic acid (1, MPUPA-OH; material manufactured by Ricerca Inc.):

<table>
<thead>
<tr>
<th>mp</th>
<th>°C (dec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR (KBr)</td>
<td>3295 (br band), 3034 (br band), 1707, 1637, 1603, 1551, 1516, 1457, 1414, 1302, 1241,1189, 1118 cm⁻¹;</td>
</tr>
<tr>
<td>H NMR (600 MHz, DMSO-d₆)</td>
<td>d 12.28 (bs, 1 H), 9.0 (s, 1 H), 7.91 (s, 1 H), 7.88 (d, J = 7.8 Hz, 1 H), 7.43 (d, J = 8.4 Hz, 2 H), 7.19 (d, J = 8.4 Hz, 2 H), 7.16 (m, 2 H), 6.94 (dd, J = 7.8, 8.4 Hz, 1 H), 3.51 (s, 2 H), 2.25 (s, 3 H);</td>
</tr>
<tr>
<td>C NMR (150 MHz, DMSO-d₆)</td>
<td>d 173.0 (C), 152.7 (C), 138.5 (C), 137.5 (C), 130.2 (CH), 129.8 (CH), 128.3 (CH), 127.5 (CH), 126.2 (CH), 122.7 (CH), 121.0 (CH), 118.1 (CH), 40.1 (CH₂), 17.9 (CH₃);</td>
</tr>
<tr>
<td>MS (EI)</td>
<td>m/z 285 (M+1) + , 193, 152, 134, 132, 109,108, 106, 93, 91, 57;</td>
</tr>
<tr>
<td>Anal. Calcd for C₁₆H₁₆N₂O₃: C, 67.59; H, 5.67; N, 9.85; Found: C, 67.60; H, 5.70; N, 10.01.</td>
<td></td>
</tr>
</tbody>
</table>


To a refluxing suspension of o-methylphenylurea phenylacetic acid (1, MPUPA-OH; 150 g, 0.501 mol; from Ricerca, Inc.) in acetonitrile (600 mL) was added thionyl chloride (41 mL, 0.558 mol) over 10 min. with vigorous stirring. Large amounts of HCl evolved. The reaction mixture was cooled to room temerature with continuous stirring for 1.5 h. The reaction mixture turned into a pink slurry to which was added solid N-hydroxysuccinimide (HOSu; 75.5 g, 0.636 mol) in one portion. To this mixture triethylamine (174 mL) was added dropwise over 30 min while the temperature of the reaction mixture was maintained below 60 °C with a water bath. Stirring was continued for 2 h and then distilled water (500 mL) was added to the reaction mixture. The solid was filtered and washed with 2 L of distilled water, and acetonitrile (2 x 200 mL), air-dried, and further dried over P₂O₅ under vacuum (~0.1 mmHg) to give crude product (175 g, 97% yield) as a beige powder. The crude product (174 g) was recrystallized from acetonitrile (3.5 L) with charcoal (10 g) decolorization to give 129 g of MPUPA-OSu (2; 68 % yield) as a white powder (purity > 99%). mp 211.2 - 211.8° C; IR (KBr): 3905-3203 (br band), 1816, 1783, 1654, 1368, 1204, 1116, 1021 cm⁻¹; H NMR (300 MHz, DMSO-d₆): d 9.04 (s, 1 H), 7.92 (s, 1 H), 7.82 (d, 1 H), 7.44 (d, J = 8.5 Hz, 2 H), 7.24 (d, J = 8.5 Hz, 2 H), 7.15 (m, 2 H), 6.93 (dd, J = 7.4, 7.3 Hz, 1 H), 4.02 (s, 2 H), 2.80 (s, 4 H), 2.23 (s, 3 H); MS (EI) m/z 382 [(M+1) + ], 239, 108, 106. |

Physical Data for succinimidyl Boc-(L)-proline (Boc-Pro-OSu, 3; material obtained from Bachem Bioscience):

<table>
<thead>
<tr>
<th>mp</th>
<th>°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR (KBr)</td>
<td>3456, 3290, 1731, 1619, 1561, 1541, 1497, 1454, 1395, 1337, 1259, 1202, 1118, 1060 cm⁻¹;</td>
</tr>
<tr>
<td>H NMR (300 MHz, CDCl₃)</td>
<td>d 4.51 (dd, J = 3.8, 8.7 Hz, 1 H), 3.56 (m, 1 H), 3.44 (m, 1 H), 2.80 (s, 4 H), 2.32 (m, 1 H), 2.27 (m, 1H), 1.94 (m, 2 H), 1.43 (s, 9H); MS (EI) m/z 335 (M+N₂)⁺, 279, 213, 138, 114, 86;</td>
</tr>
<tr>
<td>HPLC</td>
<td>97.1 %.</td>
</tr>
</tbody>
</table>

Physical Data for Benzyl-(R)-3-aminobutyrate hemisulfate (4; material obtained from Celgene Corp.):

<table>
<thead>
<tr>
<th>mp</th>
<th>°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR (KBr)</td>
<td>3515, 3383, 2989, 2945, 2880, 1821, 1788, 1744, 1701, 1476, 1454, 1421, 1394, 1368, 1260, 1241, 1202, 1159, 1077 cm⁻¹;</td>
</tr>
<tr>
<td>H NMR (300 MHz, CDCl₃)</td>
<td>d 7.85 (bs, 2 H), 7.26 (s, 5 H), 5.06 (ABq, J = 12.3 Hz, 2 H), 4.35 (m, 2 H), 3.73 (m, 1 H), 2.78 (m, 2 H), 2.10 (m, 4H), 2.00 (s, 9H); MS (EI) m/z 335 (M⁺), 279, 213, 138, 114, 86;</td>
</tr>
<tr>
<td>HPLC</td>
<td>97.1 %.</td>
</tr>
</tbody>
</table>
Preparation of N-(tert-butoxycarbonyl)-L-prolyl-3-methyl-(R)-β-alanine benzyl ester (5)

To a well-stirred suspension of benzyl-R-3-aminobutyrate hemisulfate (4; 66.7 g, 213 mmol) in CH₂Cl₂ (200 mL) were added Boc-(L)-Pro-OSu (3; 53.9 g, 222 mmol) and Et₃N (95 mL, 681 mmol). The reaction mixture was allowed to stir at room temperature for 2 h. The reaction mixture was partitioned between EtOAc (1.5 L) and H₂O (250 mL) and the organic layer was washed with 10% citric acid (3 x 250 mL), H₂O (250 mL), saturated sodium bicarbonate (250 mL), H₂O (250 mL), and brine (3 x 250 mL), dried over Na₂SO₄ and concentrated first on the rotavap (45 °C, ~80 mmHg) and then under high-vacuum overnight (room temperature, 16 h; ~0.2 mmHg) to provide intermediate 5 as a viscous oil (88.1 g) that contained residual EtOAc and CH₂Cl₂ (by NMR) and exhibited purity >98% (HPLC). This material was used, without further purification, in the reaction below.

Preparation of L-prolyl-3-methyl-(R)-β-alanine benzyl ester hydrochloride (6)

To intermediate 5 from the previous reaction was gradually added a solution of 4 N HCl in dioxane (240 mL). A vigorous evolution of gas ensued (caution: exothermic). The reaction mixture was allowed to stir at room temperature (2 h) and it was then concentrated first on the rotavap (45 °C, ~80 mmHg) and then under high-vacuum overnight (room temperature, 14 h, ~0.2 mmHg) to provide an extremely viscous material which was crystallized from CH₂Cl₂/Et₂O (2 h) and the obtained material was first concentrated on the rotavap (40 °C, 30 mL), H₂O (250 mL), and brine (3 x 250 mL), dried over Na₂SO₄ and concentrated first on the rotavap (45 °C, ~80 mmHg) and then under high-vacuum overnight to provide intermediate 6 as a viscous oil (88.1 g) that contained residual EtOAc and CH₂Cl₂ (by NMR) and exhibited purity >98% (HPLC). This material was used, without further purification in the reaction below.

Preparation of N-[4-[[[(2-methylphenylamino)carbonyl]amino]phenyl]acetyl]-L-prolyl-3-methyl-(R)-β-alanine benzyl ester (7)

To a solution of the HCl salt 6 (61.77 g, 189 mmol) in DMF (125 mL) was added MPUPA-OSu (2; 69.39 g, 181.9 mmol) followed by Et₃N (90 mL; pH -10). The reaction mixture was allowed to stir 3.5 h and it was then diluted with EtOAc (1 L) and extracted with H₂O (3 x 250 mL). At this point, the product began to precipitate: A 10% solution of citric acid (250 mL) followed by EtOAc (1 L) and H₂O (250 mL) and brine (3 x 250 mL) was added. The reaction mixture was allowed to stir 3.5 h and it was then diluted with EtOAc (1.5 L) and H₂O (250 mL) and brine (3 x 250 mL). With each subsequent aqueous wash, additional compound precipitated out; however washing was continued, care being taken not to lose the precipitate. Filtration provided 4.02 g of the white solid. Total yield for this reaction was 88 %.

IR (KBr): 3342, 3307, 3119, 2966, 1737, 1702, 1643, 1590, 1543, 1455, 1414, 1308, 1238, 1179 cm⁻¹;

mp 119.8 - 120.5 °C;

Analytical Calcd for C₁₆H₂₃N₂O₃Cl: C, 58.80; H, 7.094; N, 8.57; found: C, 58.85; H, 7.01; N, 8.46.

Preparation of N-[4-[[[(2-methylphenylamino)carbonyl]amino]phenyl]acetyl]-L-prolyl-3-methyl-(R)-β-Alanine benzyl ester (7)
Activity in an Ovine Model of Allergic Pulmonary Inflammation

Example 2. Activity in an Ovine Model of Allergic Pulmonary Inflammation

[0067] A solution of oMePUPA-V-OBn (7; 80.18 g) in THF/H₂O (9:1; 800 mL) was hydrogenated at -55 psi in the presence of Pd/C (10%); 2.44 g). After 25 h, the reaction mixture was filtered through Solka Floc® (144 g; Fiber Sales & Development Corp.) on a sintered-glass funnel. The filtrate was then refiltered through another pad of Solka Floc®. The white powder was first allowed to dry, then on the sintered glass funnel with suction (1 h, 80 mmHg) and then in the vacuum-oven (25 h; 45 °C; pressure adjusted to 25 inHg vacuum via N₂ flow). The white lumps were recrystallized from acetone/H₂O (3:2 mixture of rotamers (peaks for the major conformation): δ 12.21 (bs, 1H), 8.99 (s, 1H), 7.91 (s, 1H), 7.87 (d, J = 8.2 Hz, 1H), 7.68 (d, J = 7.9 Hz, 1H), 7.40 (d, J = 8.6 Hz, 2H), 7.17 (d, J = 5.9 Hz, 2H), 7.15 (d, J = 6.6 Hz, 3H) and (peaks for minor conformation): δ 12.21 (bs, 1H), 8.99 (s, 1H), 7.90 (s, 1H), 7.87 (d, J = 8.2 Hz, 1H), 7.18 (d, J = 7.9 Hz, 1H), 7.15 (d, J = 5.9 Hz, 2H), 7.12 (dd, J = 7.3, 7.3 Hz, 1H), 6.94 (dd, J = 7.3, 7.3 Hz, 1H), 4.22 (dd, J = 3.3, 8.8 Hz, 1H), 4.06 (m, J = 6.6 Hz, 1H), 3.47 (dd, 1H), 3.44 (d, J = 15.0 Hz, 1H), 3.37 (dd, 1H), 3.29 (d, J = 15.4 Hz, 1H), 2.46 (dd, 1H), 2.27 (m, 1H), 2.25 (s, 3H), 1.99 (m, 1H), 1.80m (m, 1H), 1.78 (m, 1H), 1.75 (m, 1H), 1.07 (d, J = 6.6 Hz, 3H) and (peaks for the minor conformation): δ 12.21 (bs, 1H), 8.99 (s, 1H), 7.90 (s, 1H), 7.87 (d, J = 8.2 Hz, 1H), 7.18 (d, J = 7.9 Hz, 1H), 7.15 (d, J = 5.9 Hz, 2H), 7.12 (dd, J = 7.3, 7.3 Hz, 1H), 6.94 (dd, J = 7.3, 7.3 Hz, 1H), 4.34 (dd, J = 1.8, 8.4 Hz, 1H), 4.18 (m, J = 6.6 Hz, 1H), 3.60 (m, 2H), 3.59 (m, 1H), 3.48 (m, 1H), 2.47 (dd, J = 6.6, 15.4 Hz, 1H), 2.40 (dd, J = 6.6, 15.4 Hz, 1H), 2.25 (s, 3H), 2.15 (m, 1H), 1.83 (m, 1H), 1.91 (m, 1H), 1.77 (m, 1H), 1.12 (d, J = 6.6 Hz, 3H); 1³C NMR (150 MHz, DMSO-d₆) (peaks for the major conformation): δ 172.4 (C=O), 170.9 (C=O), 169.3 (C=O), 152.6 (C=O), 138.2 (C), 137.5 (C), 130.2 (CH), 129.8 (CH), 129.6 (CH), 128.7 (CH), 126.1 (CH), 122.6 (CH), 120.9 (CH), 118.0 (CH), 117.9 (CH), 59.7 (CH), 46.6 (CH₂), 41.7 (CH₂), 40.6 (CH₂), 40.2 (CH₂), 29.4 (CH₂), 22.2 (CH₂), 19.9 (CH₃); 17.9 (CH₃); 13.9 (C₃); MS (EI) m/z 579 [M+Na]+, 557, 454, 426, 357, 336, 293, 267, 201; Anal. Calcd. for C₃₂H₃₆N₄O₅: C, 69.05; H, 6.52; N, 10.07; found: C, 68.87; H, 6.52; N, 9.93.

Preparation of N-[4-[(2-methylphenylamino)carbonyl]amino][phenyl]acetyl]-L-propyl-3-methyl)-(R)-β-Alanine (8; oMePUPA-V)

Example 2. Activity in an Ovine Model of Allergic Pulmonary Inflammation

[0068] Allergic sheep weighing between 27-50 kg were used. All sheep had previously been shown to develop both early and late bronchial responses to inhaled nebulized Ascaris suum allergen. The sheep were conscious and were restrained in a modified shopping cart in the prone position with their heads immobilized. After topical anesthesia of the nasal passages with 2% lidocaine, a balloon catheter was advanced through one nostril into the lower esophagus. The animals were intubated with a cuffed endotracheal tube through the other nostril using a flexible fiberoptic bronchoscope as a guide. All protocols used in this study were approved by the Mount Sinai Medical Center Animal Research
Airway responsiveness to carbachol (PC 400) assessed before, and at 24 h after allergen challenge, was expressed and LAR curves were computed for each animal using the trapezoidal rule. Significant reductions in area under the response (LAR) that evolved over the approximately 4-8-hour period after allergen challenge. Areas under the EAR values are expressed as means ± standard error of the mean. Change in SR L was calculated for each sheep as the difference from pre-challenge baseline SR L. Post-challenge changes in SR L were characterized by an early airway response (EAR) which evolved over the approximately 0-4-hour period. This was followed by a late airway response (LAR) that evolved over the approximately 4-8-hour period after allergen challenge. Areas under the EAR and LAR curves were computed for each animal using the trapezoidal rule. Significant reductions in area under the EAR or LAR curves compared to placebo control were taken to be therapeutic effects on allergen-induced changes in SR L. Airway responsiveness to carbachol (PC 400) assessed before, and at 24 h after allergen challenge, was expressed as a PC 400 ratio (post/prechallenge PC 400 values) for each sheep. A significant increase in the PC 400 ratio compared to placebo control was taken to be a therapeutic effect. Comparisons to placebo control were made using one-way analysis of variance followed by Dunnett’s test (1-tailed) for multiple comparison to a control. Comparisons that resulted in p<0.05 were taken to be statistically significant.

Figure 1 shows aerosolized oMePUPA-V’s inhibitory dose-response in Ascaris suum-sensitive sheep challenged 2 h after dosing. Left panels display change in specific lung resistance SR L, cm H2O/sec. Right panels display airway responsiveness to inhaled carbachol (PC 400 ratio, pre/post-challenge) determined at 24 h after challenge. oMePUPA-V at doses of 0.01 and a 0.03mg did not inhibit early or late airway response or alter hyperresponsiveness to carbachol at 24 h after allergen challenge. Doses of 0.1, 1 and 3 mg inhibited the early airway response and maximally inhibited the late airway response. These doses also inhibited the hyperresponsiveness to carbachol at 24
h after allergen challenge. The statistical analysis of this data is shown in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dose (mg)</th>
<th>Vehicle</th>
<th>n</th>
<th>EAR (ΔSLR x h)</th>
<th>LAR (ASLR x h)</th>
<th>PC400 (Post/Pre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dosed 2 Hours prior to Allergen Challenge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBS oMePUPAV</td>
<td>0.01</td>
<td>EtOH:NS</td>
<td>2</td>
<td>5.85 ± 0.62</td>
<td>4.85 ± 0.69</td>
<td>0.49 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>0.03</td>
<td>EtOH:NS</td>
<td>2</td>
<td>6.87 ± 0.05</td>
<td>5.11 ± 1.46</td>
<td>0.44 ± 0.04</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>EtOH:NS</td>
<td>4</td>
<td>10.62 ± 3.91</td>
<td>3.98 ± 0.23</td>
<td>0.43 ± 0.00</td>
</tr>
<tr>
<td></td>
<td>1.00</td>
<td>EtOH:PBS</td>
<td>2</td>
<td>2.14 ± 0.70</td>
<td>0.27 ± 0.34</td>
<td>1.05 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>3.00</td>
<td>EtOH:PBS</td>
<td>2</td>
<td>2.47 ± 0.62</td>
<td>0.68 ± 0.07</td>
<td>1.07 ± 0.08</td>
</tr>
</tbody>
</table>

Sheep, naturally sensitive to *Ascaris suum*, were challenged with an aerosol of *Ascaris suum* allergen 2 h after aerosol administration of oMePUPA-V at the doses indicated or 24 h after the last dose of repeated daily administration for 4 days of a subthreshold dose of oMePUPA-V or the equivalent amount of PBS. Pulmonary mechanics, reported as the change in specific airways resistance from the pre-study baseline value, were measured for 8 hours post-allergen challenge. Early Airway Response (0-4 h, EAR) and Late Airway Response (4-8 h, LAR) are expressed as the mean area under the Δ Specific Lung Resistance curve verses time ± s.e.m. Airways resistance to inhaled carbachol was determined prior to study initiation and at 24 h post-allergen challenge. Airways responsiveness is reported as the PC400 (amount of carbachol required to increase resistance by 400%) ratio by comparison of pre-challenge and post-challenge values.

*=p<0.05 compared to PBS control, one-way analysis of variance, followed by Dunnett’s test for multiple comparison to a control group. Indicates a statistically significant decrease in EAR or LAR, or a significant increase in PC400 ratio compared to PBS control group.

Single Dose Irritancy

[0075] None of the doses of oMePUPA-V used in the above study had an irritant effect, as reflected by the lack of change in airways resistance compared to baseline resistance, following challenge with *Ascaris suum* allergen. This is shown in Figure 2.

Repeated Dose Studies

[0076] Figure 3 illustrates that a 0.03 mg dose of oMePUPA-V, which was shown to be ineffective when used as a single dose acute pretreatment, was nevertheless protective if given once daily for 4 days, when antigen challenge was given 24 h after the last dose. The upper and lower left hand panels show that this effect was seen using two different formulations. Hyperresponsiveness to carbachol after a further 24 h was also maximally inhibited as shown in the upper and lower right hand panels of Figure 3. The protective effect of oMePUPA-V was significant against EAR and LAR and against hyperresponsiveness to carbachol and the quantitative analysis is shown in Table 3.

[0077] The results of this study indicate that a single pretreatment with a small molecule inhibitor of VLA-4, oMePUPA-V, by aerosol, can protect against allergen-induced early and late airways responses and post allergen-induced AHR in the allergic sheep model. No irritant effect on airways was seen with any of the doses of oMePUPA-V given as a single pretreatment. Results also showed that the effective dose of oMePUPA-V could be reduced with multiple treatments. Collectively these data provide strong evidence that the VLA-4 adhesion pathway plays a critical role in the pathophysiologic indicators (LAR and AHR) of the prolonged inflammatory events that are initiated in the airways of allergic sheep following allergen provocation.
Sheep, naturally sensitive to *Ascaris suum*, were challenged with an aerosol of *Ascaris suum* allergen 24 h after the last dose of repeated daily administration for 4 days of a subthreshold dose of oMePUPA-V or the equivalent amount of PBS. Pulmonary mechanics, reported as the change in specific airways resistance from the pre-study baseline value, were measured for 8 hours post-allergen challenge. Early Airway Response (0-4 h, EAR) and Late Airway Response (4-8 h, LAR) are expressed as the mean area under the Specific Lung Resistance curve versus time ± s.e.m. Airways resistance to inhaled carbachol was determined prior to study initiation and at 24 h post-allergen challenge. Airways responsiveness is reported as the PC400 (amount of carbachol required to increase resistance by 400%) ratio by comparison of pre-challenge and post-challenge values.

* = p<0.05 compared to PBS control, one-way analysis of variance, followed by Dunnett’s test for multiple comparison to a control group. Indicates a statistically significant decrease in EAR or LAR, or a significant increase in PC400 ratio compared to PBS control group.

Example 3. Activity in Models of Delayed Type Hypersensitivity

Sheep Red Blood Cell Studies

Specific pathogen-free female Balb/c mice, aged 8-10 weeks, from Jackson Labs were used for all experiments. The animals were fed food and water *ad libitum*. Sheep red blood cells (sRBC) in Alsever’s solution from the same sheep were obtained weekly from Charles River Pharm. Services (Southbridge, MA). The sRBC were pelleted by centrifugation at 1000g for 10 minutes at 4°C and any visible buffy coat removed. The cells were then washed in saline. The cell pellet was resuspended in saline and counted using a hemocytometer. The cells were diluted in phosphate buffered saline (PBS) to 2x10⁸ sRBC per mL. On Day 0, mice were sensitized by a s.c. injection of 2x10⁷ sRBC in 100 µL PBS. On Day 5, sRBC were prepared as above, but diluted in PBS to a final concentration of 4x10⁹ sRBC per ml. Of this preparation, 25 µL was injected s.c. into the right rear footpad.

For enteral administration of compound, oMePUPA-V (Lot# 2770-029) was formulated in a vehicle of 60% PEG 400 in 0.02M TRIS to a stock concentration of 5 mg/mL. Appropriate dilutions were prepared in the PEG/TRIS vehicle and administered enterally in a volume of 100 µL. The anti-VLA-4 antibody (PS/2) was diluted in saline at a concentration of 4.3 mg/kg and administered intraperitoneally in 100 µL. All treatments were administered immediately following challenge with sRBC.

Swelling of unchallenged control (left) and challenged (right) rear footpads was measured using a tension caliper from Mitutoyo (Model # 304-196, Dyer, Lancaster, PA) at 20 hours post-footpad challenge. The data are presented as the change in footpad thickness, determined by subtracting the left hind paw thickness from the right hind paw thickness. Changes in footpad thickness were compared using a two-tailed Student’s t-test.

The anti-VLA-4 antibody PS/2 at a dose of 4.3 mg/kg intraperitoneally inhibited swelling by approximately 30% whereas oMePUPA-V administered enteraly at a dose of 20 mg/kg was without effect in this model (data not shown). The efficacy of oMePUPA-V administered at a dose of 20 mg/kg by the enteral route in the sRBC-induced DTH model in mice was studied and no efficacy was observed.

Example 4. Activity in Models of Delayed Type Hypersensitivity

Contact Hypersensitivity Model

Twenty gram female virus-free Balb/c mice (Jackson Laboratories, Bar Harbor, ME) housed four to a cage in microisolator cages in Biogen's virus-free animal facility and receiving *ad libitum* mouse chow and tap water were used for all studies. Mice were anesthetized with ketamine:xylazine (90:10 mg/kg, i.p.). A 3 cm² patch of abdominal skin, xiphoid to pubis was exposed by closely shaving the fur and the skin was scrubbed with 70% ethanol. A 25 µL volume
of 0.5% DNFB in 4:1 v/v acetone:olive oil vehicle is uniformly applied to the bare abdominal skin. The skin was lightly scratched with the applying pipette tip to encourage mild inflammation. The mouse was laid supine in its cage and allowed to recover from anesthesia. Twenty four hours after the initial sensitization, mice were again sensitized with 25 µL of 0.5% DNFB in vehicle at the same abdominal skin location, again followed by light scratching with the pipette tip. The second sensitization was performed while restraining the unanesthetized mouse. On Day 5 (approximately 120 hours after the initial sensitization), a subirritant dose of the sensitizer (0.2% DNFB in 4:1 v/v acetone:olive oil vehicle) was used to challenge the immune response. Mice were anesthetized with 90:10 mg/kg ketamine:xylozine, i.p. and 10 µL of 0.2% DNFB was applied to the dorsal surface of the left ear. The right ear received a similar application of the 4:1 v/v acetone:olive oil vehicle. Over the subsequent 24 hour period, a biphasic ear swelling response evolved, as shown in Figure 4. Twenty four hours after challenge, mice were again anesthetized with ketamine:xylozine and the ear thickness of both ears measured with an engineer's micrometer to an accuracy of 10⁻⁴ inches.

[0083] Compounds (100 µL) or appropriate vehicle (Dimethylsulfoxide [DMSO] in isotonic phosphate buffered saline [PBS], 100 µL) were administered orally by gavage 4 hours after challenging the immune response on Day 5. Groups of 8 mice were used for each treatment tested. oMePUPA-V (Batch Number 2044-076) was dissolved in distilled water by the addition of 0.5% sodium phosphate buffer, pH 8.8, and 3% DMSO. The ear swelling response for each mouse was calculated as the difference between its vehicle- and DNFB-challenged ear thickness at 24 hours after challenge. Typical DNFB-induced ear swelling was 65-75 x 10⁻⁴ inches. Inhibition of the ear swelling response was determined by comparison of treated groups with their vehicle control group. Statistical significance of the difference among treatment groups was evaluated using one-way analysis of variance followed by Dunnett's test for multiple comparisons to a control group (Systat, SPSS Inc.) using p<0.05. Values are expressed as means ± standard error of the mean (SEM).

[0084] Figure 4 compares ear swelling responses measured 24 hours after DNFB challenge in mice that received vehicle (DMSO, PBS), positive control compound (given at 0.03 µg/kg), or 0.03 or 0.3 mg/kg oMePUPA-V, dosed enterally 4 hours after DNFB challenge (upper panel). Treatment-induced percents inhibition are shown in the lower panel. Both doses of oMePUPA-V significantly inhibited the ear swelling response to an extent similar to that shown by the positive control compound.

[0085] Single enteral 0.03 or 0.3 mg/kg doses of oMePUPA-V given 4 hours after DNFB challenge can significantly inhibit the ear swelling response in a model of mouse contact hypersensitivity.

Example 5. BIOCHEMISTRY

5.1 Receptor affinity of oMePUPA-V as measured using VCAM-Ig Alkaline Phosphatase Conjugate in VCAM-Ig Direct Binding Assay (DBA)

[0086] VCAM-Ig was constructed and purified as published (Jakubowski, A. et al. Cell Adhesion and Communication 3:131-142, 1995). Conjugation to calf intestinal alkaline phosphatase, for purposes of cleaving a chromogenic substrate, was performed as published (Lobb, R.R. et al. Cell Adhesion and Communication 3:385-397, 1995). Binding to VLA-4 was assessed on the human T cell line, Jurkat (α4β1). VCAM-Ig-AP and oMePUPA-V competed for binding to α4β1 on the surface of these cells in the presence of 1 mM Mn⁴⁺.

[0087] In the VCAM-Ig Direct Binding Assay, oMePUPA-V competes with VCAM-Ig-AP for binding to Jurkat cells in the presence of 1 mM MnCl₂, concentration-dependently, with an IC50 of 8 ± 1 nM (n=9). Results are shown in Table 4.

5.2 Receptor affinity of oMePUPA-V as measured using VCAM-Ig Alkaline Phosphatase Conjugate in the Purified VLA-4 Protein/Protein Assay

[0088] VLA-4 was purified from a detergent extract of a high expressing subclone of K562 cells by antibody affinity chromatography and immobilized on microtiter wells to establish a protein/protein competitive binding assay. VCAM-Ig-AP was bound to the purified VLA-4-coated plate in the absence or presence of oMePUPA-V (Lot #2) and 1 mM MnCl₂. Plates were read at 405 nm and the data were analyzed using SoftMax v. 2.32 software.

[0089] Binding of the VCAM-Ig conjugate to purified VLA-4 was blocked completely by a specific neutralizing anti-α4 monoclonal antibody (HP1/2). Two IC50's obtained for oMePUPA-V in the VLA-4 Protein/Protein Assay are tabulated in Table 4 as are the IC50's obtained on Jurkat cells from the VCAM-Ig-AP Competitive Binding Assay and CS1 Cell Adhesion Assay.

5.3 Receptor affinity of oMePUPA-V as assessed in the CS1 cell adhesion assay a. Adhesion of Jurkat cells to CS 1/BSA conjugate

[0090] The peptide NH₂-cysteine-tyrosine-CS-1 was synthesized and coupled to BSA-SMCC (SMCC is a heterobifunctional crosslinker which reacts with free amino groups on BSA and the sole cysteine of the synthetic peptide) at a
CS 1/BSA ratio of 10:1. Wells were coated overnight with 100 μL of conjugate diluted to a final concentration of 1 μg/ml. The next day the wells were blocked with BSA in PBS for one hour and then washed three times.

[0091] The human T cell line, Jurkat, was labeled with 2 μM BCECF-AM, a fluorescent dye (2', 7', bis-(2-carboxyethyl)-5 and -6) carboxy fluorescein acetoxymethyl ester (Molecular Probes Inc., Eugene, Oregon; catalog #B-1150) that is internalized and deesterified thus trapping the dye within live cells. Jurkat cells (1 x 10⁵ cells/well) in buffer containing 1 mM Mn⁺² were added to the coated plates in the presence of three-fold serial dilutions of inhibitor. Each concentration was assayed in duplicate. After 30 minutes at room temperature, the plates were inverted and washed three times or until no cells were adherent to control wells coated with BSA alone. CS1-adherent cells were quantitated in a Cytofluor fluorescent platereader using an excitation wavelength of 485 nm and an emission wavelength of 530 nm.

[0092] Cells adhered to CS1/BSA in the absence of compound served as the 0% inhibition control whereas cells adhering to BSA alone served as the 100% inhibition control. IC50's were calculated using Deltagraph software, version 5.

[0093] Adhesion of labeled Jurkat cells in the presence of Mn⁺² was blocked completely by EDTA and the neutralizing anti-α4β1 mAb, HP1/2, indicating that binding was specific. Table 4 gives the activity of oMePUPA-V in the CS1/BSA adhesion assay, as well as the binding assay results.

[0094] oMePUPA-V is a potent VLA-4 antagonist in buffers containing Mn⁺². It is 80-fold more potent when assayed in the presence of Mn⁺² on isolated VLA-4 than on Jurkat cells in the binding assay. oMePUPA-V is a functional antagonist as revealed by its ability to dose-dependently and completely block adhesion of Jurkat to CS1. The absolute values in the adhesion assay are greater than those observed in the binding assays. This may be due to the multivalent nature of adhesion. In all assay formats, inhibition of binding by EDTA and HP1/2 demonstrate specific binding to VLA-4.

Table 4.

| Receptor affinity of oMePUPA-V in the presence of 1 mM MnCl₂ as measured in VCAM-Ig Competitive Binding Assay, the CS1 cell adhesion assay and purified VLA-4 Protein/Protein Assay |
|---------------------------------|------------------|
| Assay                          | IC50 ± SD [nM]   |
| Jurkat cell VCAM-Ig Binding    | 8 ± 1 (n=9)      |
| Jurkat cell CS1 adhesion       | 22 ± 2 (n=4)     |
| Purified VLA-4 VCAM-Ig binding | 0.1 (n=2) (0.1, 0.1) |

6.4 Specificity of oMePUPA-V inhibition

a. Specificity of oMePUPA-V as assessed using JY cells in the VCAM-Ig Direct Binding and CS I Adhesion Assays

[0095] Binding to α4β7 was assessed on JY cells in the presence of Mn⁺². In the binding assay, VCAM-Ig and oMePUPA-V compete for binding to α4β7 on JY cells (See section 4.1.1 for assay protocol). In the cell adhesion assay, oMePUPA-V was tested for its ability to block JY (α4β7) cell binding to CS1/BSA conjugate

[0096] oMePUPA-V does not block α4β7 binding to VCAM-Ig or CS1/BSA. The anti-β7 Mab, Fib27 (Pharmingen), inhibited these interactions completely indicating that binding was α4β7 specific. Therefore oMePUPA-V is a specific inhibitor for VLA-4. Results are tabulated in Table 5.

b. Specificity of oMePUPA-V as assessed using adhesion of K562 cells to wells coated with Fn-120

[0097] Untreated 96 well polystyrene flat bottom plates were coated with 5 μg/ml Fn-120 overnight at 4°C. The plates were washed twice with phosphate buffered saline (PBS) and blocked with 1 % Bovine Serum Albumin (BSA) for 1 hour at room temperature. The plates were washed twice with TBS buffer containing 1 mM MnCl₂ (assay buffer). K562 cells were labeled with 2 μM of the fluorescent dye, BCECF-AM (see section 4.1.3), and bound to the plate for 30 minutes at room temperature. The plates were inverted and washed three times and adherent cells were quantitated in a Cytofluor fluorescent platereader using an excitation wavelength of 485 nm and an emission wavelength of 530 nm.

[0098] Adhesion of K562 to Fn-120 was completely blocked by the neutralizing anti-β5 antibody, IIA1 (Pharmingen), indicating specific binding through VLA-5. There was no inhibition of K562 cell binding to the Fn120K fragment by oMePUPA-V in doses as high as 100 μM: See Table 5 below.
c. Aggregation assays performed to assess the specificity of oMePUPA-V Methods

Activity against gpIIbIIIa was assessed by means of standard platelet aggregometry using platelet rich plasma. ADP was used to initiate aggregation in the presence of plasma where Ca^{+2} and Mg^{+2} are the major divalent cations. GRGDSP @ 100 µg/mL was used as a positive control.

Results

oMePUPA-V was tested at three doses 1, 10 and 100 µM. It did not inhibit platelet aggregation as induced by ADP, at any dose. Results are listed in Table 5. oMePUPA-V is highly (> 10,000 fold) specific for VLA-4. It has no measurable activity (> 100 µM) against the related integrins, α4β7 and VLA-5 or against the β3 integrin, gpIIbIIIa.

Table 5:

<table>
<thead>
<tr>
<th>Cell Line</th>
<th>Ligand</th>
<th>Divalent cation</th>
<th>oMePUPA-V IC50 ± SD [nM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>JY (α4β7)</td>
<td>VCAM-Ig DBA</td>
<td>Mn^{+2}</td>
<td>3% inhibition @ 100 µM (n=3)</td>
</tr>
<tr>
<td>JY (α4β7)</td>
<td>CS1/BSA adhesion</td>
<td>Mn^{+2}</td>
<td>no inhibition @ 100 µM (n=4)</td>
</tr>
<tr>
<td>K562 (VLA-5)</td>
<td>Fn-120 adhesion</td>
<td>Mn^{+2}</td>
<td>no inhibition @ 100 µM (n=3)</td>
</tr>
<tr>
<td>platelets (IibIIIa)</td>
<td>fibrinogen aggregation</td>
<td>Ca^{+2}/Mg^{+2}</td>
<td>no inhibition @ 100 µM (n=1)</td>
</tr>
</tbody>
</table>

Example 6. Assay of oMePUPA-V for LIBS Induction

6.1. Measurement on Jurkat using LIBS antibody 9EG7

LIBS induction by α4β1 antagonists was assayed in vitro by FACS analysis. Jurkat cells (2 x 10^5/well) were preincubated at 37°C for 20 minutes with TRIS-buffered saline containing 2 mM MgCl_2 (Mg^{+2}-TBS) alone or with serial dilutions of test compounds. The samples were transferred to an ice bath and supplemented with LIBS antibody, 9EG7, at a final concentration of 10 µg/ml. The cells were washed twice with Mg^{+2}-TBS and resuspended in a 1:200 dilution of a FITC conjugated-goat anti-rat IgG in Mg^{+2}-TBS and incubated for 30 min at 4°C. The cells were washed twice and resuspended in Mg^{+2}-TBS. Mean fluorescence intensity (MFI) was determined by FACS analysis (Becton Dickinson FACScan). Results are expressed as MFI. Data were analyzed by Microsoft Excel v5.0 and Deltagraph v4.0 software.

Fig. 5 shows that oMePUPA-V induced the exposure of the LIBS epitope as compared to 2 mM Mg^{+2} buffer (Panel B). The induction was concentration dependent and similar in magnitude to the induction observed with 1 mM Mn^{+2} (Panel A). Omission of the LIBS antibody and detecting antibody, or omission of the detecting antibody alone, eliminated labeling (Panel B). The ED50 of the response was ~20 nM. Conclusion

These data indicate that oMePUPA-V induces the same conformational change in VLA-4 as observed with native ligands. The LIBS values generally fall within the range defined by the binding and adhesion assays which are 8 nM and 22 nM, respectively, for oMePUPA-V.

6.2 The Multi-species Receptor Screen

Receptor affinity of oMePUPA-V as measured in VCAM-Ig Direct Binding Assay using VCAM-Ig Alkaline Phosphatase Conjugate and peripheral blood lymphocytes or spleen cells from various species.
PBLs, were isolated from peripheral blood of humans, sheep and dogs using methods described for sheep PBL (Abraham, W. M. et al. J. Clin. Invest. 93:776-787, 1994). The VCAM-Ig-AP Competitive Binding Assay was used to compare the binding of oMePUPA-V to these different cell types.

The IC50's obtained for oMePUPA-V on peripheral blood lymphocytes or spleen cells from various species in the presence of Mn+2 are shown in Table 6. In the presence of Mn+2, oMePUPA-V inhibits with a similar IC50 the binding of VCAM-Ig to lymphocytes obtained from humans, rats, dogs, sheep, and mice. There is no evidence for species specificity. This is consistent with the high degree of sequence conservation observed among species for VLA-4 and its natural ligands, CS-1 and VCAM.

<table>
<thead>
<tr>
<th>Species</th>
<th>Source</th>
<th>Divalent Cation</th>
<th>IC50 [nM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>PBLs</td>
<td>Mn+2</td>
<td>6 ± 1 (n=3)</td>
</tr>
<tr>
<td>Sheep</td>
<td>PBLs</td>
<td>Mn+2</td>
<td>3 ± 1 (n=3)</td>
</tr>
<tr>
<td>Canine</td>
<td>PBLs</td>
<td>Mn+2</td>
<td>13 ± 2 (n=3)</td>
</tr>
<tr>
<td>Mouse</td>
<td>splenocytes</td>
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</tr>
<tr>
<td>rat</td>
<td>splenocytes</td>
<td>Mn+2</td>
<td>5 ± 1 (n=3)</td>
</tr>
</tbody>
</table>

Example 7: Receptor Kinetics of oMePUPA-V

Jurkat cells were maintained in RPMI-1640 medium plus 10% fetal bovine serum at 37°C in a tissue culture incubator. For binding studies, the cells were pelleted by centrifugation, washed two times with TBS (50 mM Tris HCl, 150 mM NaCl, 0.1% bovine serum albumin, 2 mM glucose, 10 mM HEPES pH 7.4), suspended at approximately 2 x 10^6 cells/ml in TBS, and counted using a Neubauer hemocytometer. The cells were further diluted to 1.5 x 10^6/ml in the buffers indicated and subjected to the specific treatments defined for each experiment. The cells were then pelleted by centrifugation, resuspended in 100 µl of assay buffer, and transferred to a scintillation vial containing 2.9 ml of ScintiVerse n (Fisher Scientific). Cell-associated radioactivity was quantified by scintillation counting. Counts bound under these conditions measures integrin that is not occupied by the test compound and is therefore free to bind the 3H-known inhibitor. All studies were performed in siliconized 1.5 ml eppendorf tubes with a standard 1 ml sample volume. Non-specific binding of the 3H-known inhibitor to cells (background) was defined by measuring the inhibitor bound in the absence of metal ion. Specific counts bound were calculated by subtracting non-specific counts from total counts bound.

A series of competition studies were performed to verify that oMePUPA-V and the known inhibitor compete for the same site on VLA-4. First, the 3H-known inhibitor was mixed with an equimolar amount of oMePUPA-V, a 10-fold excess, and a 100-fold excess, incubated with Jurkat cells and the ability of the cold inhibitor to compete for binding of the known inhibitor assessed. oMePUPA-V treatment produced a dose-dependent inhibition of 3H-known inhibitor binding. The concentration of oMePUPA-V that was needed to compete 3H-known inhibitor binding was 10-fold greater than was needed when cold was used as a competitor, consistent with its lower affinity for Mn+2-activated VLA-4. Second, Mn+2-activated Jurkat cells were treated with 3H-known inhibitor in order to first occupy VLA-4 with the radioactive probe and then excess cold oMePUPA-V was added. Subsequent treatments with excess cold oMePUPA-V or known inhibitor were indistinguishable in their ability to displace the radioactive probe. Third, Mn+2-activated Jurkat cells were treated with saturating amounts of oMePUPA-V, and the rate at which the oMePUPA-V dissociated was measured. Unlike the prolonged half life of the known inhibitor for Mn+2-activated VLA-4, oMePUPA-V is rapidly released from the oMePUPA-V-VLA-4 with a t_1/2 of less than 10 min. The large difference in t_1/2 for oMePUPA-V and the known inhibitor suggests that the lower affinity of oMePUPA-V for VLA-4 is a result of its faster off rate.

Dissociation data reveals that binding of oMePUPA-V to VLA-4 is highly dependent on the activation state of VLA-4 and that it exhibits the same selectivity for activation seen with the known inhibitor. As with Mn+2-activated VLA-4, the t_1/2 of oMePUPA-V dissociation from Mg+2-activated VLA-4 was less than 10 min the shortest time point that can be assessed in the competition format. On the other hand, in the presence of Mg+2 plus the activating antibody, TS2/16, the t_1/2 was prolonged (20 min). All of the possible activation states have not been assessed in detail, however a simple screen was devised that can rapidly highlight differences. In this assay, a fixed concentration of oMePUPA-V
(10 nM) was mixed with 5 nM 3H-known inhibitor and binding was performed under these conditions at various states of activation. If oMePUPA-V had an abnormally high or low affinity for VLA-4 one would detect this by the difference in the amount of 3H-known inhibitor. The differences in percentage of 3H-known inhibitor bound under different activation conditions approximate what would be predicted based on the known properties of the inhibitor.

[0110] The binding studies verify that oMePUPA-V competes with the known inhibitor for binding to VLA-4 at concentrations consistent with its affinity and demonstrate that the two compounds compete for the same site on the integrin. The similarity of oMePUPA-V and the known inhibitor binding under various states of VLA-4 activation, suggest that the mechanism of binding is similar.

7.2 Assay of oMePUPA-V in Panlabs and Cerep screens

[0111] oMePUPA-V was tested in the Panlabs ProfilingScreen, DiscoveryScreen, and Immunoscreen panel of radioligand, enzyme, and functional assays and in the Cerep membrane receptor panel No significant activity was observed for oMePUPA-V at 10 μM in any assay including the NK1 receptor assay, against which known inhibitors showed some activity.

[0112] Cerep also reported oMePUPA-V showed no inhibition against human ACE protease activity. The source of ACE proteases was human endothelial cells (HUVEC). 3H-HGG, added to HUVEC, was converted to 3H-hippuric acid and glycylglycine by ACE. Captopril, a potent ACE inhibitor, blocked the conversion with an IC50 of 990 μM, while, oMePUPA-V at 10 μM, did not.

Pharmaceutical Properties:

[0113] oMePUPA-V is a white to off-white crystalline powder. It is soluble in DMSO and has an aqueous solubility of 0.120 mg/mL. The thermal behavior of oMePUPA-V studied by DSC, TGA and hot stage microscopy indicates that the material melts at approximately 160°C. At approximately 136°C the DSC and TGA analyses suggest that oMePUPA-V loses a volatile impurity which maybe consistent with the dehydration of a monohydrate.

Formulation

Nebulization Formulation

[0114] The manufacturing directions for 100 mL of a 5 mg/mL oMePUPA-V nebulization formulation are listed below. Prepare 200 mL stock buffer solution as follows:

1. Weigh 0.286 g of Tromethamine, USP into a suitable container.
2. Weigh 1.676 g of Sodium Chloride, USP into the same container.
3. Add 200 mL of Water for Injection, USP.

Mix until homogenous.

1. Weigh 0.500 g of oMePUPA-V into a suitable container.
2. Add 100 mL of buffer prepared in step 1.
3. Mix until homogeneous.
4. Sterile filter into a suitable container.
5. Seal with a suitable closure.

Typical formulation properties:

pH: 7.4, Osmolality: 290 mOsm
EXAMPLE 9: Stability Indication HPLC Procedure

Column: Zorbax® SB-C 18, 3 µm particle, 4.6 x 150 mm
Guard Column: Zorbax® SB-C18, 5 µm particle, 4.6 x 12.5 mm
Flow Rate: 1 mL/min
Column Temperature: 40 °C
Autosampler Temperature: 4 °C

Mobile Phase

A : 0.1 % (w/v) trifluoroacetic acid (TFA) in water
B : 0.1 % (w/v) TFA in 90 % (v/v) acetonitrile, 10 % (v/v) water

Gradient:

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>% B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>15</td>
</tr>
<tr>
<td>3-18</td>
<td>15 to 100</td>
</tr>
<tr>
<td>18-21</td>
<td>100</td>
</tr>
<tr>
<td>21-28</td>
<td>15</td>
</tr>
</tbody>
</table>

Injection: 10 µL of 0.2 mg/mL solutions in Tris/NaCl/water (bulk intermediate) or in 0.1 % TFA/45 % acetonitrile (final product).
Detection: UV 254 nm (primary) and 215 nm
Control: oMePUPA-V, heated in boiling water for 20 min.

The preliminary method qualification was completed.

Drug Substance Stability

No degradation was observed in the bulk intermediate stored for two weeks under the following storage conditions: at 40 °C in a closed vial; at 50 °C in a closed vial; at 25 °C, RH 60 %; and at 40 °C, RH 75 %. At four weeks, one or two degradation peaks became detectable at 40 °C and 50 °C, but the level of each impurity peak was still less than 0.02 %.

Solution Stability

a) Nebulization formulation, 5 mg/mL in Tris/NaCl, stored at room temperature for two months showed early eluting degradation peaks at a total level of 1 % (at 254 nm) and 2-3 % (at 215 nm).

b) Heating nebulization formulation in boiling water for 20 min decreased the purity from 99.9 % to 98.7 % at 254 nm and from 100 % to 93.6 % at 215 nm.

c) The 0.2 mg/mL solution in Tris/NaCl/water at neutral pH is stable at 2-8 °C at least for a week.

Claims

1. A compound of the formula (I):
or a pharmaceutically acceptable prodrug, salt, or isomer thereof, wherein said prodrug is an ester prodrug.

2. The compound according to claim 1, wherein the compound is a prodrug.

3. The compound according to claim 1 or 2, wherein the ester prodrug is prepared by reacting the compound of formula (I) with a straight or branched C₁⁻₁₀ alcohol.

4. A pharmaceutical composition comprising a compound according to claim 1, 2 or 3, and a pharmaceutically acceptable carrier.

5. The pharmaceutical composition according to claim 4, further comprising an agent selected from the group consisting of corticosteroids, bronchodilators, antiasthmatics, antiinflammatories, antirheumatics, immunosuppressants, antimitabolites, immunomodulators, antipsoriatics and antidiabetics.

6. The pharmaceutical composition according to claim 4, further comprising a cell adhesion inhibitor compound.

7. The pharmaceutical composition according to claim 6, wherein the inhibitor compound is a VLA-4 inhibitor.

8. Use of compound according to claim 1, 2 or 3 for the preparation of a pharmaceutical composition for preventing, inhibiting, or suppressing cell adhesion.

9. The use according to claim 8 for preventing, inhibiting, or suppressing inflammation.

10. Use of a compound according to claim 1, 2, or 3 for the preparation of a pharmaceutical composition for treating asthma, allergic rhinitis, multiple sclerosis, atherosclerosis, inflammatory bowel disease, or multiple myeloma.

11. Use of a compound according to claim 1, 2, or 3 for the preparation of a pharmaceutical composition for treating multiple sclerosis.

12. Use of a compound according to claim 1, 2, or 3 for the preparation of a pharmaceutical composition for treating inflammatory bowel disorders.

13. Use of a compound according to claim 1, 2, or 3 for the preparation of a pharmaceutical composition for treating, preventing or ameliorating the symptoms of asthma.

14. Use of a compound according to claim 1, 2, or 3 for the preparation of a pharmaceutical composition for treating, preventing, alleviating or suppressing diseases or disorders mediated by the VLA-4 pathway.

**Patentansprüche**

1. Verbindung mit der Formel (I):
oder ein pharmazeutisch verträgliches Prodrug, Salz oder Isomer davon, wobei das Prodrug ein Ester-Prodrug ist.

2. Verbindung nach Anspruch 1, wobei die Verbindung ein Prodrug ist.

3. Verbindung nach Anspruch 1 oder 2, wobei das Ester-Prodrug hergestellt wird, indem die Verbindung der Formel (I) mit einem geraden oder verzweigten C_1-10-Alkohol zur Reaktion gebracht wird.

4. Arzneimittel umfassend eine Verbindung nach Anspruch 1, 2 oder 3 und einen pharmazeutisch verträglichen Träger.


6. Arzneimittel nach Anspruch 4, weiterhin umfassend eine Zelladhäsion-Inhibitorverbindung.

7. Arzneimittel nach Anspruch 6, wobei die Inhibitorverbindung ein VLA-4-Inhibitor ist.

8. Verwendung einer Verbindung nach Anspruch 1, 2 oder 3 für die Herstellung eines Arzneimittels zur Prävention, Hemmung oder Unterdrückung von Zelladhäsion.


10. Verwendung einer Verbindung nach Anspruch 1, 2 oder 3 für Herstellung eines Arzneimittels zur Behandlung von Asthma, allergischer Rhinitis, Multipler Sklerose, Atherosklerose, Reizkolonsyndrom oder Multiplem Myeloma.

11. Verwendung einer Verbindung nach Anspruch 1, 2 oder 3 für die Herstellung eines Arzneimittels zur Behandlung von Multipler Sklerose.

12. Verwendung einer Verbindung nach Anspruch 1, 2 oder 3 für die Herstellung eines Arzneimittels zur Behandlung von Reizkolonenerkrankungen.

13. Verwendung einer Verbindung nach Anspruch 1, 2 oder 3 für die Herstellung eines Arzneimittels zur Behandlung, Prävention oder Verbesserung der Symptome von Asthma.

14. Verwendung einer Verbindung nach Anspruch 1, 2 oder 3 für die Herstellung eines Arzneimittels zur Behandlung, Prävention, Linderung oder Unterdrückung von Erkrankungen oder Störungen, die von dem VLA-4-Reaktionsweg vermittelt werden.

Revendications

1. Composé de la formule (I):

![Chemical Structure]

ou un promédicament, sel ou isomère pharmaceutiquement acceptable de celui-ci, dans lequel ledit promédicament est un promédicament de type ester.

2. Composé selon la revendication 1, dans lequel le composé est un promédicament.
3. Composé selon la revendication 1 ou 2, dans lequel le promédicament de type ester est préparé en faisant réagir le composé de la formule (I) avec un alcool en C\textsubscript{1-10} à chaîne droite ou ramifiée.

4. Composition pharmaceutique comprenant un composé selon la revendication 1, 2 ou 3 et un véhicule pharmaceutiquement acceptable.


6. Composition pharmaceutique selon la revendication 4, comprenant en plus un composé inhibiteur de l'adhérence cellulaire.

7. Composition pharmaceutique selon la revendication 6, dans laquelle le composé inhibiteur est un inhibiteur du VLA-4.

8. Utilisation d'un composé selon la revendication 1, 2 ou 3 pour la préparation d'une composition pharmaceutique destinée à prévenir, inhiber ou supprimer l'adhérence cellulaire.

9. Utilisation selon la revendication 8 pour prévenir, inhiber ou supprimer l'inflammation.

10. Utilisation d'un composé selon la revendication 1, 2 ou 3 pour la préparation d'une composition pharmaceutique destinée à traiter l'asthme, la rhinite allergique, la sclérose en plaques, l'athérosclérose, les entéropathies inflammatoires ou les myélomes multiples.

11. Utilisation d'un composé selon la revendication 1, 2 ou 3 pour la préparation d'une composition pharmaceutique destinée à traiter la sclérose en plaques.

12. Utilisation d'un composé selon la revendication 1, 2 ou 3 pour la préparation d'une composition pharmaceutique destinée à traiter les entéropathies inflammatoires.

13. Utilisation d'un composé selon la revendication 1, 2 ou 3 pour la préparation d'une composition pharmaceutique destinée à traiter, prévenir ou améliorer les symptômes de l'asthme.

14. Utilisation d'un composé selon la revendication 1, 2 ou 3 pour la préparation d'une composition pharmaceutique destinée à traiter, prévenir, soulager ou supprimer des maladies ou des troubles à médiation par le canal du VLA-4.
FIGURE 1
Figure 2

Peak Specific Lung Resistance (cm H₂O/sec)

- Baseline
- Postchallenge

Dose (mg)
- oMePUPA-V
- Ascaris

0 1 2 3 4 5

0.01 0.03 0.1 1 3
Figure 3
FIGURE 4A

Ear Swelling Response

Net DNFB-Induced Ear Swelling (x 10^4 in.)

VEH +CTRL 0.03 0.3
Treatment

FIGURE 4B

% Inhibition

% inhibition

+CTRL 0.03 0.3
Treatment

FIGURE 4