Multitarget Drugs: Synthesis and Preliminary Pharmacological Characterization of Zileuton Analogues Endowed with Dual 5-LO Inhibitor and NO-Dependent Activities

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(Article begins on next page)
Multitarget Drugs: Synthesis and Preliminary Pharmacological Characterization of Zileuton Analogues Endowed with Dual 5-LO Inhibitor and NO-Dependent Activities


The leukotrienes (LTs) are a family of lipid-derived autacoids that originate from arachidonic acid (AA). 5-Lipoxygenase (5-LO) is the key enzyme in this process. It transforms AA through a two-step process, first into 5-hydroperoxyeicosatetraenoic acid (5-HPETE), and then into unstable leukotriene A₄ (LTA₄). A two-step process, first into 5-hydroperoxyeicosatetraenoic acid (5-HPETE), and then into unstable leukotriene A₄ (LTA₄). This intermediate can be transformed either by leukotriene B₄ synthase into leukotriene B₄ (LTB₄), or by leukotriene C₄ synthase, which is a specific glutathione transferase, into peptide–lipid leukotrienes C₅, D₅, and E₅ (LTC₅, LTD₅, LTE₅).[1–3] LTs are involved in a variety of inflammatory and allergic disorders, particularly rheumatoid arthritis and inflammatory skin and bowel diseases. They also display potent bronchoconstrictor activity. Consequently, the treatment of allergic disorders and asthma are the classical indications for 5-LO inhibitors.[4,5] Novel and interesting potential indications are emerging for these products; for example, an increasing amount of experimental evidence shows an involvement of the 5-LO pathway in tumor cell proliferation.[6] In particular, inhibition of 5-LO was found to induce apoptosis in various cancer cell types.[6] The evidence that LTs are involved in atherosogenesis and arterial wall remodeling sets the stage for new strategies in treating the development and progression of atherosclerosis.[5,7,8] 5-LO inhibitors can be classified into four different classes according to their mechanism of action: reductase-active compounds, competitive reversible inhibitors, inhibitors of 5-LO activating protein (FLAP), and iron-chelating inhibitors. Many substances that belong to these classes were developed as potent 5-LO inhibitors, including natural products.[9–11] Among them, only (±)-[1-(1-benzo[b]thien-2-yl)ethyl]-1-hydroxyurea (1, zileuton), a hydroxyurea derivative of the iron-ligand-type inhibitor class, entered into the market in 1996 as an anti-asthmatic drug.[12,13] The commercially available product is a racemic mixture of R and S enantiomers, both of which display in vitro 5-LO inhibitor activity.

A number of studies have been carried out in recent years to design 5-LO inhibitors with dual activity: 5-LO/cyclooxygenase (COX) inhibitors have received particular attention as anti-inflammatory agents, and compounds either with dual 5-LO/thromboxane A₂ synthase inhibitory activity or with 5-LO inhibitor and platelet-activating factor (PAF) receptor antagonist mixed properties have also been developed.[10] These are examples of multitarget drugs, which should be able to modulate more than one target simultaneously; their development represents an alternative approach to using drug cocktails especially in the treatment of complex diseases such as atherosclerosis and inflammation. The most common strategy to obtain these products is the combination of two appropriate drugs, or their crucial parts, into a single molecule.[10] To our knowledge there has not yet been any documented examples of nitric oxide (NO) donor/5-LO inhibitor hybrids, despite the clear interest in such a combination. Indeed, NO is a physiological messenger that triggers a variety of actions in different systems.[15] In particular, it plays very important roles in the cardiovascular system in maintaining a number of homeostatic responses: preservation of endothelial integrity, arterial blood vessel dilation including pulmonary arterial vascularulature, inhibition of platelet adherence and aggregation, attenuation of leukocyte adherence, and activation and inhibition of vascular smooth muscle cell proliferation.[16] NO also triggers relevant action in airways, inducing relaxation of airway smooth muscle, pro-inflammatory or anti-inflammatory effects, and regulation of mucociliary clearance.[17,18] The use of NO donors in the treatment of cardiovascular disease (CD) is well known, while the therapeutic potential of these kinds of products in the field of respiratory disease is still under examination.[16–18] Herein we propose new dual-action products, obtained by combining zileuton with NO donor nitrooxy or furoxan moieties.

The synthesis of the final products required the preliminary preparation of a number of intermediates (Scheme 1). The substituted benzothiophene 3 was easily obtained by treating 6-hydroxybenzothiophene (2) with n-butyl lithium and anhydrous acetaldehyde in THF at −20 °C. The triflates 8–11 were prepared by the action of trifluoromethanesulfonfyl anhydride in dichloromethane on the appropriate nitrooxy-substituted alcohols 4–7 in the presence of 2,6-lutidine at −40 °C and were immediately used. Treatment of 3 with sodium hydride in THF, followed by the appropriate triflates 8–11 in dichloromethane afforded the expected nitrates 14–17. The action of 37% hydrochloric acid on these products dissolved in THF/water in the presence of hydroxyurea at 50 °C afforded the target com-
The furoxan derivatives 22 and 23 were prepared by reaction of 3 with the respective 4-bromomethylfurans 12 or 13 in dry DMF in the presence of potassium carbonate. The final furoxan models 24 and 25 were obtained from 22 and 23 by following the same procedure used to prepare the analogous nitric esters 18–21 from 14–17.

The ability of the target products 18–21, 24, 25, and of the reference compound zileuton to inhibit 5-LO was assessed by incubating each compound in heparin-treated human whole blood. After a fixed time, LT biosynthesis was initiated by addition of the calcium ionophore A23187, and terminated by rapid cooling of the blood. After centrifugation, the plasma level of LTBA was analyzed by enzyme-linked immunosorbent assay (ELISA). All the products were capable of relaxing the contracted tissue in a concentration-dependent manner, and the maximum response was determined with (-)-isoprenaline at 10 μM. The potencies of the products, expressed as EC50, are listed in Table 1; these figures fall in the narrow concentration range of 15–37 μM. In the nitric acid ester series, the mononitrooxy derivatives 18 and 19 display the same activity and are half as potent as the equipotent dinitrooxy analogues 20 and 21. Between the two furoxan derivatives, only the furoxancarboxamide 25 shows an EC50 value in the micromolar range, while the methyl-substituted furoxan 24 does not elicit any myorelaxing effect when tested up to 30 μM. As expected, zileuton also does not trigger any effect boxamid 25 is the least active of the series, with a potency about tenfold lower than that of zileuton, whereas its methyl analogue 24 is only fourfold less potent than the reference. Altogether, these data indicate that hybridization of zileuton with appropriate NO donor moieties affords compounds with good levels of 5-LO inhibition.

The myorelaxation effects of the target products were assessed on rat tracheal rings pre-contracted with 1 μM carbachol. All the products were capable of relaxing the contracted tissue in a concentration-dependent manner, and the maximum response was determined with

![Scheme 1](image)

**Scheme 1.** Reagents and conditions: a) nBuLi, acetaldehyde, THF (anhyd), −20 °C; b) trifluoromethanesulfonfyl anhydride, 2,6-lutidine, CH2Cl2 (anhyd), −40 °C, N2; c) NaH, THF (anhyd), −10 °C, N2; d) trifluoromethanesulfonfyl anhydride, 2,6-lutidine, CH2Cl2 (anhyd), −40 °C, N2; e) hydroxyurea, HCl (37%), H2O/THF, 50 °C. 

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**Table 1.** Vasodilation, myorelaxation, and 5-LO inhibition properties of zileuton (1) and compounds 18–21, 24, and 25.

<table>
<thead>
<tr>
<th>Compd</th>
<th>R</th>
<th>Vasodilation EC50 (mM)</th>
<th>Myorelaxation IC50 (mM)</th>
<th>5-LO Inhibition IC50 (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>0.039 ± 0.007 (&gt;30)</td>
<td>37 ± 5 (10)</td>
<td>1.6 (1.3–2.0)</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>0.023 ± 0.003 (&gt;30)</td>
<td>36 ± 8 (10)</td>
<td>2.0 (1.6–2.5)</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>0.015 ± 0.004 (23 ± 3)</td>
<td>16 ± 3 (10)</td>
<td>5.8 (4.3–7.7)</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>0.027 ± 0.004 (14 ± 4)</td>
<td>15 ± 1 (10)</td>
<td>2.8 (2.0–4.1)</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>28 ± 2 (10)</td>
<td>6.3 (4.9–8.3)</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>0.18 ± 0.04 (6.4 ± 0.7)</td>
<td>24 ± 2 (10)</td>
<td>17.9 (11.5–28.0)</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>0.04 (6.4 ± 0.7)</td>
<td>24 ± 2 (10)</td>
<td>17.9 (11.5–28.0)</td>
</tr>
</tbody>
</table>

[a] Determined on rat thoracic aorta pre-contracted with 1 μM phenylephrine. [b] Determined on rat tracheal rings pre-contracted with 1 μM carbachol. [c] Measured as the ability of the compound to inhibit biosynthesis of LTBA in human whole blood challenged with the calcium ionophore A23187. [d] Inactive at the maximum concentration tested (30 μM).
on the contracted tissue, suggesting that the myorelaxing effects observed for all the active products are mediated by NO. To confirm this hypothesis, the activity of the products on pre-contracted tracheal rings was assessed in the presence of 10 μM 1H-[1,2,4]oxadiazolo[4,3-a]quinolin-1-one (ODQ), a well-known inhibitor of soluble guanylate cyclase (sGC). This is the key enzyme in mediating tracheal relaxation induced by NO and NO-related compounds through elevation of the intracellular concentration of guanosine 3’,5’-cyclic monophosphate (cGMP).[20] The suppression of sGC activity, when the products were tested up to a concentration of 30 μM, is in keeping with the involvement of the NO messenger in their myorelaxing action. The NO-dependent myorelaxing potency of the products is near their 5-LO inhibition potency range. This means that the hybrids display these two activities in vitro in a fairly well-balanced manner.

The vasodilator effects of the target hybrids were assessed with denuded rat aorta strips pre-contracted with phenylephrine. The vasodilator potencies of the products, expressed as EC50, are also listed in Table 1. The nitrooxy-substituted compounds are very potent vasodilators, with EC50 values in the sub-micromolar range. In the nitric ester series, the products display similar potencies, ranked in the order: 20 > 19 > 21 > 18. The furoxancarboxamide 25 is also quite a potent vasodilator, about tenfold less potent than dinitrooxy ester 20, the most potent derivative of the series, and 150-fold more potent than the methyl furoxan 24. The significant decrease in activities observed when the experiments were repeated in the presence of 1 μM ODQ is in keeping with a NO-mediated vasodilator mechanism. Altogether, these data indicate that in vitro NO-mediated vasodilator effects of the tested compounds dominate their 5-LO inhibitor capacity. The only exception is methylfuroxan 24, for which these two activities occur at similar concentrations.

All the target products, including zileuton (1) as reference, were tested on carrageenan-induced paw edema in conscious rats. The injection of carrageenan into the hind paw produced swelling, which reached its maximum at 5–6 h. Zileuton (30 mg kg−1 i.g.) significantly decreased paw edema at 3, 4, and 5 h from carrageenan injection. Maximum inhibition was achieved at 3 h: 41.01 ± 5.40% relative to corresponding control values. The inhibitory activity of the compound was well maintained throughout the duration of the experiment (Figure 1). This is in line with previous data showing that both 5-LO inhibitors and LT receptor antagonists are effective against carrageenan-induced inflammation and pain.[21,22] The inflammatory reaction to carrageenan involves activation of neutrophils and mast cells, both of which are the predominant source of chemoattractant LTB4 and peptide–leukotrienes.[21,22] Compound 18, administered at a dose (45.12 mg kg−1 i.g.) equimolar to zileuton, induced a significant inhibition of paw edema, displaying the same activity as the lead (Figure 1). Compound 25 (49.94 mg kg−1 i.g.) significantly decreased (~20%) edema at 4 h only, while at the other time points it showed a trend toward inhibition, although its effect did not reach statistical significance. All the other analogues proved to be ineffective. The dose dependence of the activity of zileuton in the carrageenan-induced paw edema test[22] indicates that higher doses of the present series of zileuton analogues should be tested. However, these experiments were precluded by the low solubility of the products in the vehicle (Figure 1).

Notably, while the compounds at the doses tested differ in their anti-inflammatory activity, they display similar in vitro 5-LO inhibition potency, suggesting a different pharmacokinetic profile between the compounds.

In conclusion, a number of hitherto unknown hybrid products, obtained by combining zileuton with either NO donor nitrooxy or furoxan moieties, were designed and evaluated as dual 5-LO inhibitors, rat tracheal ring myorelaxing agents, and vasodilators of rat aorta strips pre-contracted with phenylephrine. The products display 5-LO inhibitory activity in the micromolar range, close to where NO-dependent myorelaxing effects are observed. In contrast, their NO-dependent vasodilator effects occur in the sub-micromolar range, with the sole exception of the methyl-substituted furoxan derivative 24, which is active at micromolar concentrations. Altogether, the in vitro results reported herein indicate that this new class of dual 5-LO inhibitors/NO donors could find interesting applications in the treatment of airway and inflammatory diseases, as well as in the management of atherosclerosis development and its progression.

Preliminary characterization of in vivo pharmacological activity showed that compound 18, namely zileuton substituted at the 6-position with the simple 3-nitrooxypropoxy chain, exhibits anti-inflammatory activity near that of the lead 1, when tested in the carrageenan-induced rat paw edema assay. Compound 25, bearing a (3-carbamoylfuroxan-4-yl)methoxy group at the 6-position, also displays significant activity after 4 h. Because solubility limitations preclude administration of higher doses in this experimental model, additional in vivo studies are necessary to fully evaluate the potential of this series of compounds.

![Figure 1. Percent increase in carrageenan-induced paw edema in rat. The compounds were administered by intragastric route at doses equimolar with zileuton (1, 30 mg kg−1), and their effects were evaluated at 2, 3, 4, and 5 h from carrageenan injection. **p < 0.01, *p < 0.05 vs. control (Dunnett’s test).](image)
Experimental Section

Melting points (mp) were measured on a capillary apparatus (Büchi 540); mp with decomposition was determined after placing the sample in a bath at a temperature 10 °C below the mp; a heating rate of 3 °C/min was used. All compounds were routinely checked by FTIR (PerkinElmer SPECTRUM BXII), ¹H and ¹³C NMR (Bruker Avance 300), and mass spectrometry (Finnigan-Mat TSQ-700). Flash column chromatography was performed on silica gel (Merck Kieselgel 60, 230–400 mesh ASTM) using the eluents indicated. Thin-layer chromatography (TLC) was carried out on 5 x 20 cm plates with 0.25 mm layer thickness. Anhydrous MgSO₄ was used as drying agent for the organic phases. Analysis (C, H, N) of the new compounds was performed by REDOX (Monza); the results are within ±0.4% of theoretical values. Compounds 2, 20, 21, 12, 22 and 13 were synthesized by following published methods. Tetrahydrofuran (THF) was distilled immediately before use from sodium and benzophenone.

1-(6-Hydroxybenzo[b]thiophen-2-yl)ethanol (3). nBuLi (1.6 M in hexane, 25 mL, 3 equiv) was added at < -20 °C to a stirred solution of compound 2 (2.00 g, 13 mmol) in anhydrous THF (80 mL) under N₂, and the mixture was stirred for 3 h at 0 °C. Anhydrous acetalddehyde (1.72 g, 2.2 mL, 40 mmol) was then added. The reaction mixture was warmed to 50 °C under N₂, and the resulting solution was allowed to warm to room temperature over 2 h. The mixture was quenched with saturated NH₄Cl solution over 2 h. The mixture was quenched with saturated NH₄Cl and the solution was allowed to warm to room temperature over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.

General method for the preparation of triflates 8–11

A solution of compound 6 (1.00 mmol) was cooled to -30 °C and a solution of LiHMDS (3.00 mmol, 1.0 equiv) was added portion-wise to a solution of triflic anhydride (1.50 mmol, 1.5 equiv) in anhydrous THF (25 mL) under N₂, and the resulting mixture was stirred at 0 °C for 1 h. The solution was quenched with saturated NH₄Cl solution over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.

A solution of compound 7 (1.00 mmol) was cooled to 0 °C and a solution of NaH (1.25 mmol, 1.25 equiv) in THF (25 mL) was added portion-wise to a solution of triflic anhydride (1.50 mmol, 1.5 equiv) in anhydrous THF (25 mL) under N₂, and the resulting mixture was stirred at 0 °C for 1 h. The solution was quenched with saturated NH₄Cl solution over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.

A solution of compound 8 (1.00 mmol) was cooled to 0 °C and a solution of NaH (1.25 mmol, 1.25 equiv) in THF (25 mL) was added portion-wise to a solution of triflic anhydride (1.50 mmol, 1.5 equiv) in anhydrous THF (25 mL) under N₂, and the resulting mixture was stirred at 0 °C for 1 h. The solution was quenched with saturated NH₄Cl solution over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.

A solution of compound 9 (1.00 mmol) was cooled to 0 °C and a solution of NaH (1.25 mmol, 1.25 equiv) in THF (25 mL) was added portion-wise to a solution of triflic anhydride (1.50 mmol, 1.5 equiv) in anhydrous THF (25 mL) under N₂, and the resulting mixture was stirred at 0 °C for 1 h. The solution was quenched with saturated NH₄Cl solution over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.

A solution of compound 10 (1.00 mmol) was cooled to 0 °C and a solution of NaH (1.25 mmol, 1.25 equiv) in THF (25 mL) was added portion-wise to a solution of triflic anhydride (1.50 mmol, 1.5 equiv) in anhydrous THF (25 mL) under N₂, and the resulting mixture was stirred at 0 °C for 1 h. The solution was quenched with saturated NH₄Cl solution over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.

A solution of compound 11 (1.00 mmol) was cooled to 0 °C and a solution of NaH (1.25 mmol, 1.25 equiv) in THF (25 mL) was added portion-wise to a solution of triflic anhydride (1.50 mmol, 1.5 equiv) in anhydrous THF (25 mL) under N₂, and the resulting mixture was stirred at 0 °C for 1 h. The solution was quenched with saturated NH₄Cl solution over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.

A solution of compound 12 (1.00 mmol) was cooled to 0 °C and a solution of NaH (1.25 mmol, 1.25 equiv) in THF (25 mL) was added portion-wise to a solution of triflic anhydride (1.50 mmol, 1.5 equiv) in anhydrous THF (25 mL) under N₂, and the resulting mixture was stirred at 0 °C for 1 h. The solution was quenched with saturated NH₄Cl solution over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.

A solution of compound 13 (1.00 mmol) was cooled to 0 °C and a solution of NaH (1.25 mmol, 1.25 equiv) in THF (25 mL) was added portion-wise to a solution of triflic anhydride (1.50 mmol, 1.5 equiv) in anhydrous THF (25 mL) under N₂, and the resulting mixture was stirred at 0 °C for 1 h. The solution was quenched with saturated NH₄Cl solution over 2 h. The mixture was worked up and concentrated in vacuo. The residue was purified by flash chromatography (PE/EtOAc 1:3) to give 3 as a white solid (2.00 g, 13 mmol) in 85% yield.
9.19 ppm (s, 1 H, OH); 13C NMR (75 MHz, [D6]DMSO): δ = 17.7, 28.2, 52.2, 63.7, 72.0, 77.9, 105.7, 114.0, 120.7, 123.8, 133.1, 140.3, 143.5, 155.4, 161.3 ppm; IR (KBr): 3345, 3230, 2941, 1659, 1646, 1601, 1578, 1466, 1273, 1227, 1150, 1064, 845 cm⁻¹; MS (EI, 70 eV) m/z (%): 385 (17), 340 (20), 295 (27), 263 (100), 207 (75); Anal. calc for C17H22N4O9S (430.39): C 41.86, H 4.22, N 13.02; found: C 42.33, H 4.02, N 13.18.

6-(2-[1-Carbamoylhydroxyamino]ethyl)-1-benzo[b thiophen-6-yl]oxy)hexan-1,2-diyldinitrate (21). The title compound was obtained as was 19 by starting from 11, through the intermediate 17. The title compound was purified by flash chromatography (CH2Cl2/EOAc 7:3) to give a white solid (30%); mp: 105–107 °C (dec., EtOAc/hexane 7:3). 1H NMR (300 MHz, [D6]DMSO): δ = 1.46 (d, J = 7 Hz, 3 H, CH3), 1.54–1.60 (m, 2 H), 1.73–1.83 (m, 4 H) (CC(C)=C), 4.02 (t, J = 6 Hz, 2 H, CH2OC), 4.72 (dd, J = 13 Hz, J = 6 Hz, 2 H, CH2ON), 4.95 (dd, J = 13 Hz, J = 2 Hz, 1 H, CH2ON), 5.42–5.47 (m, 1 H, CONH), 5.50 (q, J = 7 Hz, 1 H, CH2CH3), 6.43 (s, 2 H, NH2), 6.93 (dd, J = 9 Hz, J = 7 Hz, 1 H, H5), 7.14 (s, 1 H, H3), 7.44 (d, J = 2 Hz, 1 H, H7), 7.63 ppm (d, J = 9 Hz, 1 H, H4); 13C NMR (75 MHz, [D6]DMSO): δ = 17.7, 21.1, 27.9, 28.1, 52.2, 67.3, 71.2, 80.2, 105.5, 114.1, 120.7, 123.7, 132.8, 140.4, 151.3, 159.9, 161.3 ppm; IR (KBr): ν = 3465, 3196, 2939, 2870, 1659, 1572, 1465, 1270, 1225, 1152, 844 cm⁻¹; MS (EI) m/z (%): 459 (1) [M+H]+, 414 (100); Anal. calc for C15H18N4O9S (430.39): C 41.86, H 4.22, N 13.02; found: C 42.33, H 4.02, N 13.18.

A solution of hydroxyurea (112 mg, 1.5 mmol, 1.5 equiv) in H2O (7 mL) was added to a solution of N-[(4-({2-[(1-Carbamoylhydroxyamino)ethyl]-1-benzo[b thiophen-6-yl]oxy)methylfuroxan-3-carboxamide (25) Compound 12 (289 mg, 1.5 mmol, 1 equiv) was added portion-wise to a solution of 3 (194 mg, 1.0 mmol, 1 equiv) and K2CO3 (552 mg, 4.0 mmol, 4.0 equiv) in DMF (anhdy, 1.5 mL) and the reaction mixture was stirred at room temperature for 1 h. Ice water was then added, and after separation of the layers the aqueous layer was extracted with EtOAc. The combined organic layers were washed with H2O and brine, dried over anhydrous MgSO4, and concentrated under reduced pressure. The residue was purified by flash chromatography (CH2Cl2/EOAc 8:2) to give 23 as a white solid (201 mg, 60%); 1H NMR (300 MHz, [D6]DMSO): δ = 1.46 (d, J = 6 Hz, 3 H, CH3), 4.99 (m, 1 H, CH), 5.46 (s, 2 H, CH2O), 5.66 (d, J = 5 Hz, 1 H, OH), 7.06 (dd, J = 2 Hz, J = 9 Hz, 1 H, H5), 7.14 (s, 1 H, H3), 7.63 (d, J = 2 Hz, 1 H, H7), 7.66 (d, J = 9 Hz, 1 H, H4), 7.85, 8.50 ppm (2 s, 2 H, NH2); 13C NMR (75 MHz, [D6]DMSO): δ = 26.3, 62.5, 65.6, 107.7, 111.4, 115.2, 118.9, 124.8, 135.0, 140.7, 151.7, 155.7, 156.2, 156.6 ppm; MS (EI, 70 eV) m/z (%): 335 (30) [M]+, 317 (2), 193 (100), 175 (60).

A solution of hydroxyurea (112 mg, 1.5 mmol, 1.5 equiv) in H2O (7 mL) was added to a solution of 23 (335 mg, 1.0 mmol, 1 equiv) in THF (10 mL), and this reaction mixture was warmed to 50 °C. HCl (2 M, 300 mL, 30 equiv) was then added. The cooled reaction mixture was warmed to 50 °C for 2 h, and then concentrated under reduced pressure. From the cooled aqueous solution precipitated a solid that was triturated and filtered. The obtained crude 25 was purified by flash chromatography (CH2Cl2/PyOH: 9:1) to give a white solid (160 mg, 46%): mp: 175–176 °C (dec., EtOAc/EOAc); 1H NMR (300 MHz, [D6]DMSO): δ = 1.49 (d, J = 7 Hz, 3 H, CH3), 5.46 (s, 2 H, CH2O), 5.52 (q, J = 7 Hz, 1 H, CH3), 6.44 (s, 2 H, NH2), 7.05 (dd, J = 2 Hz, J = 9 Hz, 1 H, H5), 7.18 (s, 1 H, H3), 7.65 (d, J = 2 Hz, 1 H, H7), 7.68 (d, J = 9 Hz, 1 H, H4), 7.85, 8.50 ppm (2 s, 2 H, NH2). 13C NMR (75 MHz, [D6]DMSO): δ = 28.7, 52.2, 63.7, 72.0, 77.9, 105.7, 114.0, 120.7, 123.8, 133.1, 140.4, 155.5 ppm; MS (EI) m/z (%): 348 (35), 334 (60), 318 (95), 323 (50), 190 (82), 177 (100); Anal. calc for C14H10N2O3S (393.38): C 45.80, H 3.84, N 17.80; found: C 45.81, H 4.03, N 17.53.

Leukotriene assay. Studies of 5-LO inhibition were carried out by following a procedure similar to that reported previously.[60] Blood samples were obtained from healthy volunteers who had not taken any drug for at least two weeks. Volunteers gave their informed and signed consent to the use of blood samples for research purposes. Methanolic solutions of the tested compounds at various concentrations were prepared, 10 μL aliquots were distributed in incubation polystyrene tubes, and the solvent was evaporated. The residues were dissolved by vortexing in 1 mL heparinized (20 IU mL−1) venous blood, and the tubes were pre-incubated for 15 min at 37 °C. Eicosanoid biosynthesis was initiated by adding the calcium ionophore A23187 at 50 μM (final 0.05% v/v DMSO) and terminated after 30 min by rapid cooling of the blood in an ice bath and centrifuging at 3 °C for 10 min. The supernatants were further centrifuged at 12000 g at 3 °C for 3 min, and then supernatants were ready to be tested for LTB4 production. Basal LTB4 production in blood untreated with A23187 was subtracted, and percent inhibition in samples incubated with tested compounds was evaluated in comparison with control samples with maximal LTB4 production. LTB4 production was evaluated by competitive ELISA according to specific instructions provided by Cayman Chemical, based on a competition between LTB4 and an LTB4–acylcholinesterase conjugate (LTB4 tracer). At the end of an overnight incubation at 4 °C the amount of tracer (added in each well at a constant concentration) bound to antisera is inversely proportional to the added concentrations of LTB4, produced by 5-LO. This antibody–LTB4 complex binds to an unspecified antibody
that had been previously attached to the well. The plate is washed to remove any unbound reagents, and then Elman’s reagent, which contains a substrate for acetylcholinesterase, is added to the well. The product of this enzymatic reaction gives a distinct yellow color that absorbs at λ 405 nm. The intensity of this color, determined spectrophotometrically, is proportional to the amount of LT-tracers present in the well, which is inversely proportional to the amount of LTs present in the well during the incubation. A standard curve with known concentrations of LTβ is used to obtain concentrations in the sample wells. Percent inhibition in compound-treated samples was calculated by comparison with control untreated samples. The concentration of the tested compounds effecting 50% inhibition (IC50) was calculated from the concentration–inhibition response curve (3–4 experiments).

Myorelaxing activity. Tracheas and aortas were isolated from male Wistar rats weighing 180–200 g. The animals, treated humanely in accordance with recognized guidelines on experimentation, were anesthetized with CO2 and killed by decapitation. As few animals as possible were used. The purposes and the protocols of our studies were approved by the Ministero della Salute, Rome (Italy). The tissues were mounted in organ baths containing 30 mL Krebs-bicarbonate buffer of the following composition (mm): NaCl 111.2, KCl 5.0, CaCl2 2.5, MgSO4 1.2, KH2PO4 1.0, NaHCO3 12, glucose 11.1. The solution was maintained at 37 °C and continuously gassed with 95% O2/5% CO2 (pH 7.4). The tracheal tube was quickly excised and cleaned free of excess tissues, then was cut into single rings. Three to four rings were joined together by thread to form a chain and mounted under tension (1.0 g) in organ baths. After an equilibration period of 120 min, 1 μM carbachol was added to the organ bath to induce a spasm of the trachea rings, and when a constant level was reached, cumulative concentration–response curves to compounds were determined. Effects of 10 μM ODQ were evaluated in a separate series of experiments in which it was added 20 min before the contraction. With this protocol, the inhibitor is pre-incubated for at least 40 min before the start of the curve. The results are expressed as EC50 ± SE (μM); EC10 values are the mean of 4–6 determinations. Responses were recorded by an isometric transducer connected to the MacLab System PowerLab.

Vasodilator activity. The aorta endothelium was removed and the vessels were cut helically: three strips were obtained from each aorta. The tissues were mounted under tension (1.0 g) in organ baths. The aortic strips were allowed to equilibrate for 120 min and then contracted with 1 μM phenylephrine. When the response to the agonist reached a plateau, cumulative concentrations of the vasodilating agent were added. The effects of 1 μM ODQ on relaxation were evaluated in separate series of experiments in which it was added 5 min before the contraction. With this protocol, the inhibitor is pre-incubated for at least 30 min before the addition of the vasodilator compound. Results are expressed as EC50 ± SE (μM); EC10 values are the mean of 4–8 determinations.

Anti-inflammatory activity. The anti-inflammatory activity of compounds under study was tested by carrageenan-induced paw edema in conscious rats. Acute edema was induced in the right hind paw of rats by injecting into the plantar region 0.1 mL of freshly prepared solution of 1% carrageenan. The volume of the paw was measured using a plethysmograph (Basile, Italy) at 2, 3, 4, and 5 h after carrageenan challenge. Inflammation was expressed as the percentage change in paw volume.[81] Compounds under study were administered intrastrically (i.g.) in a volume of 10 mL kg−1 immediately before carrageenan injection.

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