

Specific leukotriene formation by purified human eosinophils and neutrophils

Jan Verhagen, Pieter L.B. Bruynzeel[†], Johannes A. Koedam, G. Aryan Wassink[†],
Martin de Boer*, Gerben K. Terpstra[†], Johannes Kreukniet[†], Gerrit A. Veldink
and Johannes F.G. Vliegthart

Department of Bio-Organic Chemistry, State University of Utrecht, Croesestraat 79, NL-3522 AD Utrecht,
[†] *Department of Pulmonary Disease, University Hospital, Catharijnesingel 101, NL-3511 GV Utrecht and * Central*
Laboratory of the Netherlands Red Cross Blood Transfusion Service, Plesmanlaan 125, NL-1006 AD Amsterdam,
The Netherlands

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Human granulocytes isolated from peripheral blood have been described to synthesize both LTB₄ and LTC₄ from arachidonic acid. We have observed that the amount of LTC₄ produced by human granulocyte preparations is strongly dependent on the relative amount of eosinophils. To investigate a possibly significant difference in leukotriene synthesis of the eosinophilic and neutrophilic granulocytes, we developed a purification method to isolate both cell types from granulocytes obtained from the blood of healthy donors. Leukotrienes were generated by incubation of the purified cells with arachidonic acid, calcium ionophore A23187, calcium-chloride and reduced glutathione. Surprisingly, eosinophils were found to produce almost exclusively the spasmogenic LTC₄. In contrast, neutrophils produce almost exclusively the chemotactic LTB₄, its ω -hydroxylated metabolite 20-hydroxy-LTB₄ and two non-enzymically formed LTB₄ isomers.

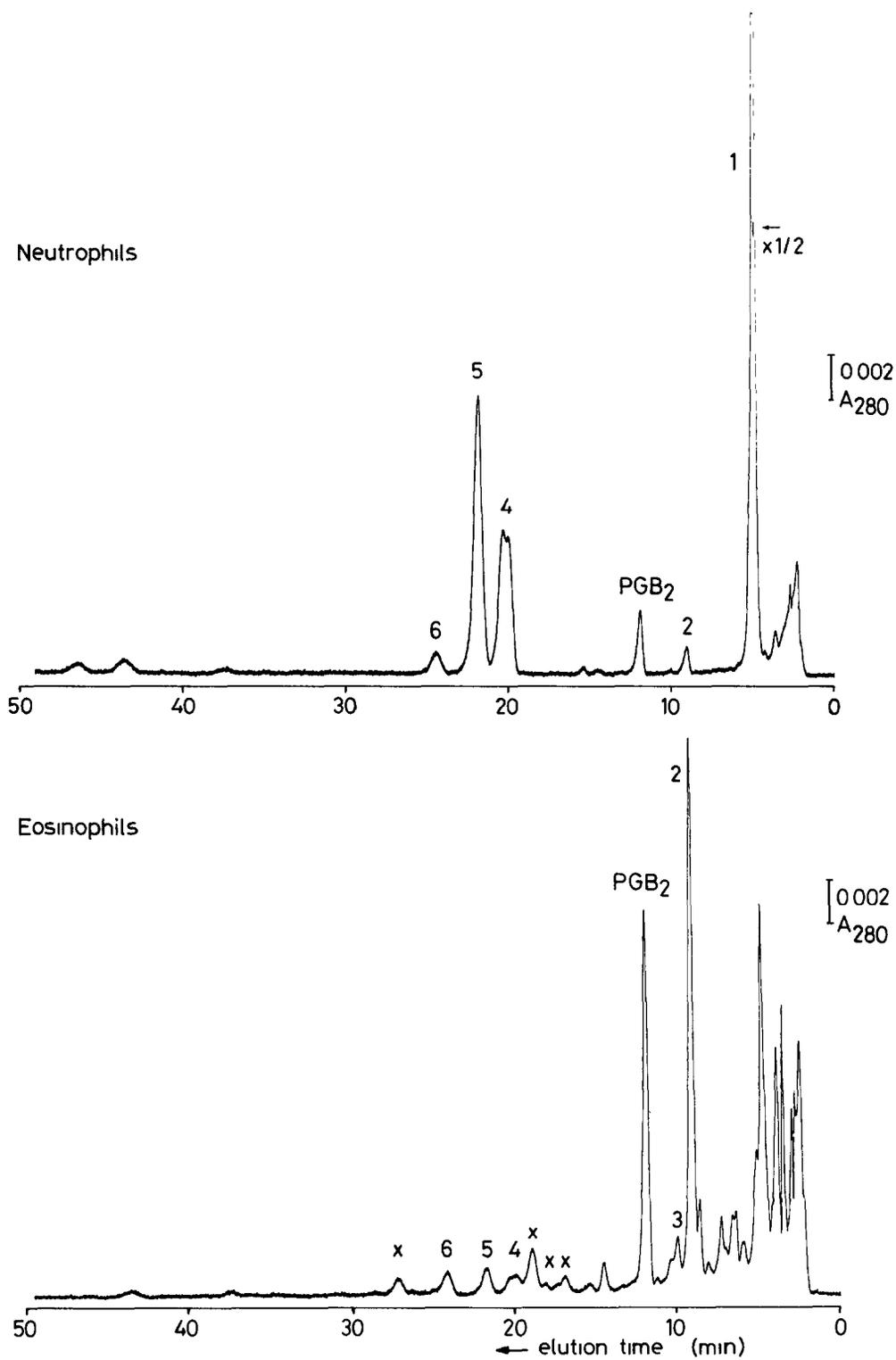
<i>Leukotriene</i>	<i>Granulocyte</i>	<i>Eosinophil</i>	<i>Neutrophil</i>	<i>Lipoxygenase</i>	<i>Asthma</i>
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1. INTRODUCTION

Leukotrienes constitute an important class of biologically active arachidonic acid metabolites, formed via the lipoxygenase pathway. Several types of human blood and tissue cell e.g., granulocytes [1,2], lymphocytes [3], macrophages [4,5] and mast cells [6], are capable of synthesizing leukotrienes from arachidonic acid. Leukotriene C₄ (LTC₄: 5(*S*)-hydroxy-6(*R*)-*S*-glutathionyl-7,9*trans*-11,14-*cis*-eicosatetraenoic acid) and leukotriene D₄ (LTD₄: 5(*S*)-hydroxy-6(*R*)-*S*-cysteinylglycyl-7,9-*trans*-11,14-*cis*-eicosatetraenoic acid) have been shown to be strongly bronchoconstrictive in vitro [7] as well as in vivo [8] and therefore may play an important role as mediators in (immediate) hypersensitivity reactions. Leukotriene B₄ (LTB₄: 5(*S*),

12(*R*)-dihydroxy-6,14-*cis*-8,10-*transeicosatetraenoic acid*) possesses a pronounced chemotactic activity for human neutrophils [9] and eosinophils [10]. Since eosinophils probably play an important role in hypersensitivity reactions, it is of interest to know whether these cells are capable of producing leukotrienes and if so whether the leukotriene formation by eosinophils differs qualitatively and/or quantitatively from the formation of leukotrienes by neutrophils.

Recently the production of leukotrienes by purified horse eosinophils [11], murine eosinophils [12] and human eosinophils [13,14] has been described. Authors in [12,13] observed that murine and human eosinophils produce leukotrienes of the 5- and 15-series in almost equal amounts. Authors in [11] reported that horse eosinophils produce



LTB₄ and LTC₄ isomers as well as about 4-times as much sulfidopeptide leukotrienes per cell as horse neutrophils. Authors in [14] found that – in the absence of added glutathione – human eosinophils produce small amounts of LTB₄, LTC₄ and LTD₄.

So far, leukotriene formation by human eosinophils and neutrophils under optimal conditions has not been compared in detail.

Here, a method has been developed to purify human eosinophils and neutrophils from granulocyte preparations obtained from quantities as small as 100 ml blood from healthy donors. The formation of leukotrienes by eosinophils and neutrophils has been compared in the presence of sufficient amounts of glutathione to enable optimal production of sulfidopeptide leukotrienes.

2. MATERIALS AND METHODS

2.1. Materials

Arachidonic acid (purity > 99%) was purchased from Fluka (Buchs, Switzerland) and Nu Chek Prep, Inc. (MN). Calcium ionophore A23187, reduced glutathione, PGB₂ and 4-hydroxy-2,2,6,6-tetramethylpiperidinoxy free radical were from Sigma (St. Louis, MO). Percoll (1.129 g/ml) and Ficoll-Paque (1.077 g/ml) were obtained from Pharmacia (Uppsala). Solvents, which were all of HPLC quality, and octadecyl reversed-phase extraction columns (6 ml) were purchased from Baker (Deventer, The Netherlands). Synthetic LTB₄, LTC₄ and LTD₄ were a kind gift of Dr J. Rokach (Merck-Frosst Laboratories, Pointe Claire/Dorval, Quebec). Human blood was obtained from healthy volunteers of the Red Cross Bloodbank Foundation (Utrecht).

2.2. Purification of granulocytes

Granulocytes were isolated as follows: platelet-rich plasma was removed after centrifugation of

citratred blood at 275 × g for 15 min. After collection of the buffy coat, granulocytes were separated from lymphocytes and monocytes by centrifugation on Ficoll-Paque at 650 × g for 20 min. The remaining erythrocytes were removed by ammonium-chloride lysis at 0°C and subsequent centrifugation.

The purity of the cell preparations was found to be better than 97%. The content of eosinophils in these preparations ranged from 2 to 8%.

2.3. Purification of eosinophils and neutrophils

Eosinophils and neutrophils were separated from each other by two subsequent centrifugations of a granulocyte preparation in isotonic Percoll solutions with densities of 1.085 and 1.088 g/ml at 1000 × g for 10 min at room temperature. 96 ± 3% pure neutrophils appeared at the top of the 1.085 g/ml Percoll solution, while the eosinophils and some neutrophils were present as a small pellet on the bottom.

After resuspension of the eosinophil pellet in a 1.088 g/ml Percoll solution and centrifugation at 1000 × g for 10 min at room temperature, 96 ± 4% pure eosinophils appeared on the bottom of the tube.

Recoveries were 37 ± 16% and 85 ± 10% for eosinophils and neutrophils, respectively (*n* = 5). Cell integrity was measured with the vital stains fluorescein diacetate and ethidium bromide [15,16]. Further support for cell integrity was obtained by the absence of lactate dehydrogenase and β-glucuronidase activities in the supernatants of isolated, unstimulated cells.

2.4. Incubation procedure

Eosinophils or neutrophils were suspended in Dulbecco's salt solution (pH 7.4) at a concentration of approx. 10⁷ cells/ml, preincubated at 37°C for 5 min and then incubated at 37°C for 5 min with 80 μM arachidonic acid, 20 μM calcium ionophore A23187, 1 mM (extra) CaCl₂ and 5 mM

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Fig. 1. RP-HPLC chromatograms of the leukotrienes produced from arachidonic acid (80 μM) by 8 × 10⁶ neutrophils (purity 99%) or eosinophils (purity 98%) isolated from the same granulocyte preparation. Solvent system: tetrahydrofuran-methanol-water-acetic acid (25:30:45:0.1, by vol.), pH 5.5, flow rate: 0.9 ml/min. UV spectra were recorded of all peaks. Synthetic LTB₄ and LTC₄ were used as references. Identification of peaks: 1, 20-hydroxy-LTB₄; 2, LTC₄; 3, 11*t*-LTC₄; 4, 12*epi*,6*t*-LTB₄ + 6*t*-LTB₄; 5, LTB₄; 6, 12*epi*,6*t*,8*c*-LTB₄ (double-dioxygenation product). X, 15-series leukotrienes. NB, the peak in the eosinophil chromatogram having a position almost identical with the 20-hydroxy-LTB₄ peak in the neutrophil chromatogram does not possess a characteristic triene UV spectrum.

reduced glutathione. Reactions were stopped by the addition of ice to the incubation mixture.

2.5. Sample preparation

The incubation mixture was centrifuged at $46\,000 \times g$ for 10 min at 4°C. For the extraction of the formed leukotrienes octadecyl (C18) reversed-phase extraction columns (6 ml) were used, which were first washed with methanol and water, respectively, according to the manufacturers instructions. After applying the cell supernatant (pH 7.4) to the column and washing with water, the absorbed leukotrienes were eluted with methanol (usually 3 ml). Recovery for all leukotrienes was found to be better than 85%.

After addition of the radical scavenger 4-hydroxy-2,2,6,6-tetramethylpiperidinoxy free radical (2 µg/3 ml), the eluates were stored under nitrogen at -70°C until they were analyzed by RP-HPLC.

2.6. Reversed-phase high-performance liquid chromatography (RP-HPLC)

Leukotrienes were separated and quantified, as

in [17] by isocratic RP-HPLC, using a Nucleosil 5C18 column (250 × 4.6 mm, Chrompack, Middelburg, The Netherlands) attached to a Perkin-Elmer Series 1 pump and a Perkin-Elmer LC85 detector. The solvent system was tetrahydrofuran-methanol-water-acetic acid (25:30:45:0.1, by vol.) which had been brought to pH 5.5 with ammonium hydroxide. The aqueous phase contained 0.1% EDTA to prevent binding of cations to the column. Such binding could lead to excessive retention of sulfidopeptide leukotrienes [18]. A flow rate of 0.9 ml/min was maintained and the effluent was monitored at 280 nm (leukotrienes) or 237 nm (monohydroxy acids). Peak areas were determined with a Hewlett-Packard 3390 A integrator and related to the internal standard PGB₂, using molar absorption coefficients ($M^{-1} \cdot cm^{-1}$) of 28 650 for PGB₂ and 40 000 for the leukotrienes at 280 nm and 29 500 for the monohydroxy acids at 237 nm [19].

3. RESULTS

Eosinophils and neutrophils were purified from

Table 1

Leukotriene formation from arachidonic acid by purified human eosinophils and neutrophils: Comparison of data of this study with those from the literature

	LTC ₄	LTD ₄	LTB ₄	20-hydroxy-LTB ₄	12 ϵ pi,6 ι -LTB ₄ + 6 ι -LTB ₄	12 ϵ pi,6 ι ,8c-LTB ₄	15-series leukotrienes	LTC ₄ + LTD ₄ + LTB ₄ + isomers	15-series 5-series
Human neutrophils (here) ^a	3 ± 3	—	29 ± 5	45 ± 8	24 ± 6	3 ± 1	—	0.03	0.00
Human eosinophils (here) ^a	35 ± 13	—	4 ± 2	—	4 ± 2	2 ± 1	5 ± 5	3.50	0.11
Eosinophils (literature) ^b									
Human [14] ^c	1.1	0.7	2.8	n.d.	10.0	n.d.	n.d.	0.14	n.d.
Human [13] ^d	n.d.	n.d.	1.8	n.d.	6.9	5.6	11.8	n.d.	0.82
Murine [12] ^e	n.d.	n.d.	1.1	n.d.	5.9	7.7	11.2	n.d.	0.76
Horse [11] ^f	11.1	1.1	6.5	n.d.	8.9	n.d.	n.d.	0.73	n.d.

^a From 5 different granulocyte preparations, eosinophils and neutrophils have been purified and stimulated; mean values (expressed as 10^6 molecules released/cell) are given ± SD

^b The literature data were originally expressed in ng leukotriene formed per 10^8 cells and were recalculated to 10^6 molecules of leukotriene formed per cell (no corrections have been made for losses during isolation)

Incubation periods: ^{d,e} and here: 5 min; ^f 15 min; ^c 20 min. ^{c,f} Glutathione has not been added; ^{d,e} LTC₄ was not taken into consideration

granulocytes obtained from 0.1 to 1.0 l human blood. Fig.1 shows RP-HPLC chromatograms of the leukotrienes formed by eosinophils or neutrophils purified from the same granulocyte preparation. The absolute quantity of each leukotriene produced per cell in 5 min is given in table 1. These data prove that almost all LTC₄ produced in vitro by human granulocytes is synthesized by the eosinophil population which accounts only for less than 5% of the granulocytes in healthy donors. On the other hand, the syntheses of LTB₄, 20-hydroxy-LTB₄ and the two non-enzymically formed LTB₄ isomers are almost exclusively due to the neutrophils. The relative amount of 20-hydroxy-LTB₄ was found to dependent on the length of the incubation period. After 20 min nearly all LTB₄ had been converted into 20-hydroxy-LTB₄. It is interesting to note that even after prolonged incubation of eosinophils 20-hydroxy-LTB₄ could not be detected.

Both neutrophils and eosinophils produce only very small amounts of the double-dioxygenation product 12*epi*,6*t*,8*c*-LTB₄ (sometimes referred to as 5S,12S-DHETE). Furthermore, eosinophils were found to produce minor quantities of leukotrienes formed from 15(*S*)-hydroperoxy-5,8,11-*cis*-13-*trans*-eicosatetraenoic acid (15HPETE), which were not formed by neutrophils under these conditions. The small amounts of the latter compounds did not allow structural characterization. However, it seems reasonable to assume that these leukotrienes are formed from 15HPETE, because the RP-HPLC chromatogram of the leukotrienes produced from 15HPETE by porcine lymphocytes shows peaks with identical retention times and UV spectra (unpublished). The major monohydroxy-eicosatetraenoic acid formed by eosinophils was 15-hydroxy-5,8,11-*cis*-13-*trans*-eicosatetraenoic acid (15HETE, elution time RP-HPLC: 67 min) whereas neutrophils were found to synthesize mainly 5-hydroxy-6-*trans*-8,11,14-*cis*-eicosatetraenoic acid (5HETE, elution time RP-HPLC: 92 min).

As 5-lipoxygenases have until now always been found to be Ca²⁺-dependent [1,20] whereas 15-lipoxygenases have not [21,22], some incubations with eosinophils and neutrophils were done in the absence of calcium ionophore and of extracellular Ca²⁺. Under these conditions the syntheses of LTC₄, LTB₄ and 5HETE were found to be strong-

ly reduced, whereas the production of 15HETE and 15-series leukotrienes by eosinophils was not affected significantly.

Therefore, the effect of Ca²⁺ supplies additional evidence that eosinophilic LTC₄ is produced via the 5-lipoxygenase pathway. Without added glutathione the production of LTC₄ by eosinophils was reduced to approx. 20% of the amount formed in the presence of 5 mM glutathione. Therefore, it must be concluded that the eosinophil shows its potent and specific capacity to produce LTC₄ in vitro only when Ca²⁺, calcium ionophore as well as glutathione are present in sufficient quantities.

4. DISCUSSION

This study demonstrates that human eosinophilic and neutrophilic granulocytes synthesize different types of leukotrienes. Until now, such a specificity for human eosinophils and neutrophils has not been reported. It is interesting to compare our results with literature data as compiled in table 1.

From these data it is obvious that the relative amounts of LTB₄, its isomers and 15-series leukotrienes formed by eosinophils have been overestimated because the production of LTC₄ has not been sufficiently stimulated [14] or LTC₄ formation has not been taken into consideration at all [12,13]. Therefore, these investigations conceal the specific potency of the eosinophil to produce large amounts of LTC₄.

Our finding that the eosinophilic granulocyte population is almost entirely responsible for the production of the spasmogenic LTC₄ by granulocytes, may throw new light on the role of the eosinophil in (immediate) hypersensitivity reactions. Frequently, asthmatic patients have high numbers of eosinophils in their lung tissue which is often reflected in an increased number of blood eosinophils. Until now, the role of the eosinophil in this disease was often regarded to be beneficial, because eosinophils have been shown to contain enzymes capable of inactivating LTC₄ [23,24] and histamine [25]. However, the here demonstrated potency of the eosinophil to produce large amounts of LTC₄ shows that – under certain conditions – this activity may prevail over a possibly beneficial activity.

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