

SULPHATED POLYSACCHARIDES HAVING ANTI-INFLAMMATORY ACTIVITY

This invention relates to compounds having anti-inflammatory activity, and in particular it relates to the use of these compounds as anti-inflammatory agents in animals and man.

One of the key events in inflammation is the adherence of leukocytes or tumour cells to blood vessel walls and their subsequent emigration into tissues. The molecular basis of these processes is poorly understood although it is generally accepted that penetration of the vessel wall requires localised degradation of the interendothelial cell junctions and subendothelial matrix by specific degradative enzymes.

It has now been discovered that continuous infusion of certain sulphated polysaccharides, such as heparin and fucoidan, can completely prevent experimental allergic encephalomyelitis (EAE), an animal inflammatory disease similar to multiple sclerosis in humans.

In a first aspect, the present invention relates to the use of certain sulphated polysaccharides as anti-inflammatory agents. In this aspect, this invention provides a method of anti-inflammatory treatment of an animal or human patient, which comprises administration to the patient of an effective amount of at least one sulphated polysaccharide which blocks endoglycosidase activity.

In another aspect, this invention relates to the use of these sulphated polysaccharides in the preparation of pharmaceutical compositions for anti-inflammatory treatment. In this aspect, there is provided a pharmaceutical composition which comprises at least one sulphated polysaccharide which blocks endoglycosidase activity, together with a pharmaceutically acceptable carrier or diluent therefor.

This invention particularly relates to the use of sulphated polysaccharides which block heparinase activity. Suitable sulphated polysaccharides include heparin, fucoidan, pentosan sulphate, dextran sulphate, and carrageenan-lambda. As previously described, one sulphated polysaccharide which has been found to exhibit endoglycosidase-inhibitory activity is heparin, and in one

particularly preferred embodiment of this invention the active component is heparin or a similar sulphated polysaccharide having anti-coagulant activity that has been appropriately modified to reduce this anti-coagulant activity. Examples of such modified polysaccharides are (a) decarboxylated heparin that has a 20 fold reduction in its anti-coagulant activity and negligible loss of anti-metastatic agent and

(b) periodate oxidized, reduced heparin that has negligible anti-coagulant activity but is a potent anti-metastatic agent. In both (a) and (b) the endoglycosidase-inhibitory activity of the polysaccharides is retained.

The following Example demonstrates the anti-inflammatory activity of the sulphated polysaccharides, heparin, fucoidan and pentosan sulphate.

EXAMPLE 1

MATERIALS AND METHODS

Rats. Lewis (RT-1¹) rats were bred at the John Curtin School of Medical Research. Both males and females of 8-10 weeks of age were used. In each experiment controls and experimental rats were matched for sex.

Induction of EAE.

Active. Guinea pig BP was prepared according to the method of Deibler et al (2) and BP in saline was emulsified in an equal volume of incomplete Freund's adjuvant containing 4 mg/ml added Mycobacterium butyricum. Rats received 0.1 ml emulsion in one footpad of both hind feet. Total dose received was 50 μ g BP and 400 μ g Mycobacterium butyricum.

Passive. Cells for passive transfer were generated following the method of Panitch and McFarlin (3) Single cell suspensions were prepared from spleens of donor rats sensitized 12 days previously with BP-CFA as described above. Cells were cultured at 2×10^6 /ml in RPMI 1640 +5% fetal calf serum, 5×10^{-5} M 2-mercaptoethanol, 200 mM L-glutamine and penicillin and streptomycin. Con A was added at 2 μ g/ml and cultures were incubated at 37°C in an atmosphere of 10% CO₂, 7% O₂ and the balance N₂. Cells were harvested after 72 hrs, washed with Hanks balanced salt solution (BSS) and transferred to recipients via a lateral tail vein. All transfer populations contained 30×10^6 viable cells.

Evaluation of clinical EAE

Clinical EAE was graded according to the following scheme: 0, asymptomatic; 1, flaccid distal half of tail; 2, entire tail flaccid; 3, ataxia, difficulty in righting; 4, hind limb weakness; 5, hind limb paralysis.

In most experiments we also calculated the mean day of onset of disease (MDO), the mean clinical score (MCS) and the mean length or duration of disease (MLD). Values are expressed standard error of the mean.

Histology

Rats were perfused with 10% neutral buffered formalin. Their spinal cords removed and prepared by standard histological techniques. Slides were stained with H and E.

Polysaccharides

Chondroitin-4-sulfate, fucoidan (from *Fucus vesiculosus*), pentosan polysulfate and heparin (sodium salt from bovine lung) were all purchased from Sigma (St. Louis, MO). The polysaccharides were dissolved in 0.15 M NaCl and stored at -20°C . They were thawed and then boiled for 2 min immediately before use.

Heparin devoid of anticoagulant activity was prepared by periodate oxidation and borohydrate reduction using a similar procedure to that described by Fransson (1). Bovine lung heparin (10 mg/ml) was dissolved in 0.05 M sodium phosphate buffer, pH 7.0, containing 40 mM sodium periodate and left to react for 18 hrs at 37°C in the dark. The reaction was stopped by the addition of solid D-mannitol (5 mg/ml) and the solution then dialyzed against distilled water at room temperature for 2 hrs, the dialysate being changed every 30 min. The oxyheparin was then reduced by the addition of solid potassium borohydride (2 mg/mg heparin), the reduction reaction being left for 3 hrs at room temperature and then terminated by the addition of glacial acetic acid (1 μ l/mg of borohydride). The heparin was then ethanol precipitated twice (2 vols ethanol, 4°C, 18 hrs) and finally dissolved in 0.15 M NaCl to a concentration of 20 mg/ml. Approximately 50% of the heparin was recovered as the periodate oxidised borohydride reduced preparation.

The anticoagulant activity of heparin and periodate oxidized heparin was determined using rat plasma in the activated partial thromboplastin time and thrombin time tests. Based on these assays periodate oxidation resulted in a 500-2000 fold reduction in the anticoagulant activity of heparin.

Delivery of sulfated polysaccharides. Because of the short half life of some of the polysaccharides in vivo we thought it necessary to give repeated doses. We first attempted ip injections of heparin every twelve hours. Unfortunately, this produced unacceptable levels of hemorrhage and even death of some animals. We chose therefore to use mini osmotic pumps (type 2ML, ALZA Corp, Palo Alto, Calif.) which were implanted subcutaneously in the back. The pumps have a 2ml capacity and deliver approximately 10 μ l/hr for 7 days. Plasma levels of heparin was measured in rats implanted with an osmotic pump containing 20 mg/ml. The method employed was essentially the dimethylmethylene blue procedure of Farndale et al (4). A steady state concentration of 10-20 μ g/ml was reached by 24 hrs after implanting the pump on day 0 and no heparin was detectable on day 8, i.e. 24 hrs after the pump ceased to deliver.

RESULTS

Recipient rats received 30×10^6 EAE effector cells and at the same time osmotic pumps were placed subcutaneously in the back. The pumps contained 2 ml of heparin at either 10 mg/ml or 20 mg/ml. As shown in Table I there was a degree of protection in both heparin treated groups. Only 3 of 6 rats receiving 10 mg/ml heparin developed disease and only 1 of 5 receiving 20 mg/ml. In the latter case, the one animal

which did develop disease did so later after cell transfer and also exhibited a milder disease.

In the next experiment we used heparin again as well as three further sulfated polysaccharides, fucoidan, chondroitin-4-sulfate, and pentosan sulfate, and also asked if initiation of treatment could be delayed for 3 days and still provide protection. Fucoidan as well as heparin gave complete protection against EAE even when treatment was delayed till day 3 after cell transfer (Table II). Pentosan sulfate gave partial protection as evidenced by later onset, milder clinical disease, and shorter duration of disease. Chondroitin-4-sulfate had no protective effect.

Often, therapeutic studies of various agents in EAE demonstrate that clinical disease may be abrogated, yet histopathologic examination will reveal quite extensive inflammatory lesions (5, 6). To examine this in the present context, 3 control and 3 heparin treated animals from the experiment described in Table II were killed on day 8 post cell transfer and examined for inflammatory lesions. Virtually every low power field of a 2 cm longitudinal section through the lower thoracic/upper lumbar cord of control rats had numerous perivascular inflammatory lesions.

In contrast, no lesions were seen in any of 80 sections from the same area of the three heparin treated rats.

To determine if the sulfated polysaccharides are inhibiting adoptive EAE by simply killing the transferred cells, we examined the ability of treated rats to exhibit memory to a challenge with BP-CFA. We (7, 8) and others (9, 10) have reported that following recovery from passively induced EAE, or in the case of neonates, in the absence of any initial disease symptoms following cell transfer (7, 8),

a later active challenge with BP-CFA leads to a much earlier onset of disease symptoms than is seen in control animals which never received EAE effector cells. The interpretation of these data is that early onset is the result of activation of memory cells which persist in the animal and arise from the original transfer population. Therefore, the animals represented in Table II were challenged with 50 g BP-CFA on day 14 after receiving the cell transfer. Control rats which had never received cells were also challenged. The results are shown in Table III. Naive animals developed disease day 10-11 after active immunization. Cell recipients on the other hand showed a memory response following challenge irrespective of treatment regimen or presence or absence of initial clinical signs, thus demonstrating that treatment did not inhibit adoptively transferred disease by killing the cells.

Is the effect that heparin, and possibly the other polysaccharides have on adoptively transferred EAE a function of their anticoagulant activity? To answer this question, anticoagulant free heparin was prepared by

periodate oxidation and borohydride reduction as described above and then tested for its EAE inhibiting activity. As seen in Table IV, all animals receiving anticoagulant free heparin developed EAE; however, there was a significant delay in onset of disease, a diminution in the clinical severity and also a decrease in the duration of the disease symptoms. These results strongly suggest that the EAE inhibiting effect of heparin is not due solely to its anticoagulating activity.

The effect of heparin on actively induced EAE was also examined and the results presented in Table V. When heparin treatment was begun at the time of sensitization there was a significant delay in the onset of disease, however, the clinical score attained or the duration of disease did not differ from controls animals. It is interesting to note that the delay of 6 days is approximately the length of time the pumps deliver heparin, 7 days.

TABLE I

Effect of heparin on adoptively transferred EAE^a

Treatment	# Rats with EAE/ Total	Mean Day of Onset	Mean Clinical Score
Control	4/4	4.3. ± 0.2	3.9 ± 0.1
Heparin ^b (10 mg/ml)	3/6	5.3 $\pm 0.3^c$	3.5 $\pm 0.2^c$
Heparin ^b (20 mg/ml)	1/5	7.0 ^c	2.5 ^c

- a. 30×10^6 Con A incubated EAE spleen cells given iv.
- b. Heparin given in osmotic pumps placed subcutaneously at time of cell transfer.
- c. Represent the score only for the animal(s) which developed clinical signs.

TABLE II

Effect of sulfated polysaccharides on adoptively
transferred EAE

Treatment	# With EAE/ Total	Mean Day Onset	Mean Clinical Score	Mean Length Disease
Control	7/7	4.4 $\pm$ 0.2	4.1 $\pm$ 0.9	5.0 $\pm$ 0.4
Heparin (20 mg/ml)	0/8	-	-	-
Fucoidan (20 mg/ml)	0/6	-	-	-
Chondroitin- 4-sulfate (20 mg/ml)	5/5	5	3.5 $\pm$ 0.2	5.0 $\pm$ 0.4
Pentosan sulfate (20 mg/ml)	5/5	6.2 $\pm$ 0.3	2.4 $\pm$ 0.2	3.0 $\pm$ 0.4

- a. Osmotic pumps containing sulfated polysaccharides were implanted day 3 after cell transfer.

TABLE III

Memory response in rats receiving sulfated
polysaccharides 3 days after adoptive transfer
of EAE effector cells

Treatment Group	# With EAE/ # Challenged ^a	Individual Day of Onset
Naive	4/4	10, 11, 11, 11
Control (cells only)	4/4	7, 7, 7, 8
Heparin	5/5	7, 7, 7, 8, 8
Fucoidan	6/6	7, 7, 8, 8, 8, 10
Chondroitin- 4-sulfate	5/5	7, 7, 8, 8, 10
Pentosan sulfate	N.D. ^b	N.D.

a. Rats challenged with 50 μ g BP-CFA on day 14 after
initial cell transfer.

b. Not determined.

TABLE IV
Effect of anticoagulant-free heparin
on passively induced EAE

Treatment	# With EAE/ Total	Mean Day Onset	Mean Clinical Score	Mean Duration Disease
Control	7/7	5.0	3.4 $\pm$ 0.1	4.0 $\pm$ 0.2
Heparin (20 mg/ml)	0/5	-	-	-
Periodate- oxidised heparin (20 mg/ml)	5/5	6.4 $\pm$ 0.2	1.6 $\pm$ 0.2	2.4 $\pm$ 0.4

TABLE V

Effect of heparin on actively induced EAE

Treatment	# With EAE/ # Challenged	Mean Day Onset	Mean Clinical Score	Mean Duration Disease
Control	5/5	11.4 $\pm$ 0.5	4.2 $\pm$ 0.3	6.6 $\pm$ 0.6
Heparin ^a (20 mg/ml)	5/5	17.6 $\pm$ 0.8	5.0	6.0 $\pm$ 0.5

a. Heparin pumps implanted at time of sensitization
with 50 μ g BP-CFA/rat.

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CLAIMS

1. Use in the manufacture of a medicament for the anti-inflammatory treatment of an animal or human patient of at least one sulphated polysaccharide which blocks or inhibits endoglycosidase activity.
2. Use according to claim 1 wherein said sulphated polysaccharide is one which blocks or inhibits heparinase activity.
3. Use according to claim 1 wherein said sulphated polysaccharide is selected from the group consisting of heparin (including modified heparin), fucoidan, pentosan sulphate, dextran sulphate and carrageenan lambda.
4. Use according to claim 1 wherein said sulphated polysaccharide is heparin.
5. Use according to claim 1 wherein said sulphated polysaccharide is heparin which has been modified to reduce its anti-coagulant activity.
6. Use according to claim 5, wherein said modified heparin is decarboxylated heparin or periodate oxidized, reduced heparin.
7. A pharmaceutical or veterinary composition for anti-inflammatory treatment which comprises at least one sulphated polysaccharide which blocks or inhibits endoglycosidase activity, other than heparin, a heparin derivative, or dextran sulphate together with a pharmaceutically or veterinarily acceptable carrier or diluent therefor.

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REPLACED



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8. A composition according to claim 7, wherein said sulphated polysaccharide is one which blocks or inhibits heparanase activity.

9. A composition according to claim 7, wherein said sulphated polysaccharide is selected from the group consisting of fucoidan, pentosan sulphate, and carrageenan lambda.