Inhibition of binding of interferon-\(\gamma\) to its receptor by salicylates used in inflammatory bowel disease

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Abstract
5-Aminosalicylic acid (5ASA), 4ASA, their N-acetylated metabolites N-acetyl-5ASA and N-acetyl-4ASA, olsalazine, and colchicine impair interferon-\(\gamma\) (IFN \(\gamma\)) induced HLA-DR expression on a colonic cell line, HT-29. The mechanism of this effect is now reported. HT-29 cells were cultured with 50 \(\mu\)M IFN \(\gamma\) with or without drug, and northern blot analysis was performed using a probe for the \(\beta\) chain of the DR molecule. IFN \(\gamma\) led to a noticeable increase in HLA-DR mRNA which was attenuated by the drugs. Analysis of the specific binding of increasing concentrations of \(^{125}\text{I-IFN }\gamma\) by non-linear regression showed a \(K_d\) of \(1.35 \times 10^{-10}\) M and \(2.3 \times 10^3\) binding sites per HT-29 cell. Binding of \(^{125}\text{I-IFN }\gamma\) was reduced by incubation with increasing concentrations of unlabelled IFN \(\gamma\) but not with IFN \(\alpha\). Incubation with therapeutic concentrations of drugs led to the following reductions in binding: 10 mM 5ASA, 20\% (p<0.001); 10 mM N-acetyl-5ASA, 24\% (p<0.01); 10 mM 4ASA, 21\% (p<0.005); 10 mM N-acetyl-4ASA, 29\% (p<0.001); and 1 mM olsalazine, 29\% (p<0.001). Colchicine (10\(^{-7}\) M) and 10\(^{-5}\) M prednisolone had no effect. Incubation with higher concentrations of the drugs revealed a dose-response effect on binding with complete inhibition by 100 mM 4ASA and 10 mM olsalazine, and lesser degrees of inhibition by 100 mM 5ASA, N-acetyl-5ASA, and N-acetyl-4ASA. At concentrations found in the rectal lumen, the salicylates used in inflammatory bowel disease impair the binding of IFN \(\gamma\) to its receptor on colonic epithelial cells.

Products of the class II genes of the major histocompatibility complex are cell surface heterodimers consisting of \(\alpha\) and \(\beta\) chains. Three major products are described in man: HLA-DR, DP, and DQ. CD4\(^+\) lymphocytes (the helper/inducer phenotype) recognize foreign antigens carried by class II molecules on antigen-presenting cells.\(^1\)

HLA-DR is constitutively expressed on B lymphocytes, some macrophages, dendritic cells, vascular endothelial cells, and some epithelial cells and can be induced in a wide range of tissues in inflammatory diseases.\(^1\) In vitro, this is generally mediated by interferon-\(\gamma\) (INF \(\gamma\)), although this effect can be enhanced by other cytokines.\(^2,5\)

In the normal gastrointestinal tract, HLA-DR is constitutively expressed on small intestinal villus cells but not in the crypts or on gastric or colonic epithelial cells.\(^6\) However, epithelial HLA-DR is induced in inflammatory condi-
dimethylsulphoxide and then diluted 1 in 1000 in L-15. All solutions were filtered before use.

Methods

NORTHERN BLOT ANALYSIS

Northern blot analysis of HLA-DR and β actin mRNA was performed in the standard manner using diethyl pyrocarbonate treated solutions. Briefly, HT-29 cells were incubated in L-15 medium containing 50 U/ml of IFN γ with or without drug for 72 hours. The cells were detached with 0-2 mg/ml trypsin (Worthington Biochemical Corporation, NJ, USA) and 10 mM EDTA in calcium- and magnesium-free Hank’s buffered salt solution and resuspended in L-15.

RNA was extracted with guanidinium thiocyanate (RNAzol B, Cinna Biotex, Friendwood, Texas, USA) and electrophoresed on a formamide/agarose gel for 12 hours at 35 V before transfer to a nitrocellolose filter. The filter was probed for HLA-DR mRNA using a probe (provided by Dr J Bell, Oxford) labelled with 125I (Oligolabelling kit, Pharmacia). After repeated washes in sodium citrate/sodium dodecyl sulphate, an autoradiograph was developed. The filter was then probed for actin (probe provided by Dr M Dallman, Oxford) in the same manner. The autoradiograph was read by eye.

IFN γ BINDING

0–10 mM

HT-29 cells were detached with trypsin/EDTA, washed twice in L-15, and counted. Cells (106) were added to 5ml Falcon polystyrene tubes (Becton Dickinson, Lincoln Park, NJ, USA), and centrifuged at 1000 g for 5 minutes. The supernatants were discarded and replaced with solutions of combinations of 125I-IFN γ, unlabelled IFN γ, IFN α, and drug dissolved in 1 ml of L-15. In most experiments, 30 nCi (45 fmol) of 125I-IFN γ were added to each tube. The tubes were then agitated for two to four hours. All binding studies were performed at 4°C to prevent receptor internalisation.

After incubation, the cells were washed three times with 2 ml L-15 and resuspended in 1ml L-15. Before counting (LKB Wallac 1260 Multi-gamma II counter) they were transferred to a second Falcon tube to exclude 125I-IFN γ bound to plastic. Four tubes without cells were included in each experiment to measure nonspecific binding. Specific binding was calculated as cpm—mean cpm of these four tubes.

Dose-response curves

To maintain constant osmolality, experiments requiring drug concentrations greater than 10 mM were performed in Dulbecco’s phosphate buffered saline (PBS) with 10% fetal calf serum (FCS). Solutions of 100 mM drug in PBS/10% FCS were made up with the concentration of NaCl reduced to maintain osmolality. Thus, for 100 mM solutions of 5ASA, N-acetyl-5ASA, N-acetyl-4ASA, acetate, propionate, and butyrate, 137 mM NaOH replaced NaCl and the pH was adjusted to 7-4 with HCl. For solutions of the sodium salts 4ASA, olsalazine, and hydrocortisone, the concentration of NaCl was simply reduced by the appropriate amount.

These solutions were mixed with PBS/10% FCS to provide a range of drug concentrations and binding studies were performed as outlined above.

Results

NORTHERN BLOT

As shown in Figure 1, IFN γ induced HLA-DR mRNA in HT-29 cells. There was a noticeable reduction in the amount of HLA-DR mRNA induced in cells incubated in 1 mM olsalazine, 10-7 M colchicine, and 10 mM 4ASA. Variation in mRNA loading was detected by hybridisation with the β actin probe. Adjustment for RNA loading suggests that IFN γ induction of HLA-DR mRNA was also reduced by 10 mM 5ASA and 10 mM N-acetyl-4ASA but not by 10 mM N-acetyl-5ASA or 10-5 M prednisolone. Apart from the lack of effect with N-acetyl-4ASA, the results suggest that these compounds are antagonising the effect of IFN γ at a pretranscriptional level. This led to an investigation of the effect of the drugs on IFN γ binding.

IFN γ BINDING

Time course

Maximal binding was attained by 120 minutes (Fig 2). All subsequent experiments were performed with 120–240 minute incubations.

Cell viability

Trypan blue exclusion was 90–100% after two hours incubation at 4°C in 10 or 100 mM 5ASA, 4ASA, N-acetyl-5ASA, and N-acetyl-4ASA and

Figure 1: Northern blot of HLA-DR and β actin mRNA in HT-29 cells incubated for 72 hours with combinations of interferon γ (INF γ) and drugs. In each lane the upper band is HLA-DR and the lower band is actin. (1) 50 U/ml IFN γ + 10-3 M colchicine, (2) 50 U/ml IFN γ + 10-4 M prednisolone, (3) 50 U/ml IFN γ + 1 mM olsalazine, (5) 50 U/ml IFN γ + 10 mM 5ASA, (6) 50 U/ml IFN γ + 10 mM N-acetyl-5ASA, (7) 50 U/ml IFN γ + 10 mM 4ASA, (8) 50 U/ml IFN γ + 10 mM N-acetyl-4ASA, (9) no IFN γ. The unlabelled lane is a loading error.

Figure 2: Time course of binding of 125I-interferon γ (INF γ) to HT-29 cells.
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Figure 3: Specific binding of 125I-interferon γ (IFN γ) to HT-29 cells. Specific binding (+) at each concentration of 125I-IFN γ was calculated by subtracting the cpm in the presence of excess unlabelled IFN γ (O) from the cpm without excess unlabelled IFN γ (X).

in 1 or 10 mM olsalazine. Viability was lowest with 10 mM olsalazine. In our previous study\(^4\) we performed simultaneous flow cytometric analysis of HLA-DR expression and propidium iodide exclusion to show that the effects of the drugs were not the result of impaired viability.

Binding isotherm
Increasing concentrations of 125I-IFN γ, with or without excess unlabelled IFN γ (30 000 U), were added to tubes containing 10\(^5\) HT-29 cells. Specific binding at each concentration was calculated by subtracting the cpm in the presence of excess IFN γ from the cpm without excess IFN γ. A representative binding curve is shown in Figure 3. Non-linear regression of the specific binding curve weighted by the inverse of the variance was performed using the Multifit computer programme on an Apple McIntosh computer. This revealed a K\(_d\) of 1.35 x 10\(^{-8}\) M and 2.3 x 10\(^{5}\) binding sites per cell (assuming one molecule of IFN γ binds to one receptor site). Similar results were obtained by analysis of a Scatchard plot.

Competition with unlabelled IFN γ and IFN α
Increasing concentrations of unlabelled IFN γ led to complete abolition of 125I-IFN γ binding. IFN α had no effect (Fig 4).

Effect of therapeutic concentrations of salicylates on IFN γ binding
The effect of each compound on 125I-IFN γ binding was studied by comparing 10 tubes in which cells were incubated in the presence of each of the drugs with 10 control tubes. The coefficient of variation was calculated for each set of 10 tubes. IFN γ binding was reduced by 20% by 10 mM 5ASA (p<0.001, unpaired Student's t test), 24% by 10 mM N-acetyl-5ASA (p<0.01), 21% by 10 mM 4ASA (p<0.005), 29% by 10 mM N-acetyl-4ASA (p<0.001), and 29% by 1 mM olsalazine (p<0.01). Prednisolone (1 x 10\(^{-5}\) M) and 10\(^{-7}\) M colchicine had no effect (Fig 5). The mean coefficient of variation was 12.7%.

Effect of increasing doses of salicylates
Increasing concentrations of 5ASA, 4ASA, their N-acetylated metabolites and olsalazine led to increasing inhibition of 125I-IFN γ binding. Olsalazine was the most potent compound, with complete inhibition of IFN γ binding to cells incubated in 10 mM olsalazine. Sulphapyridine is insoluble at higher concentrations by acetate, propionate and butyrate, the major anions in the colonic lumen, did not alter binding. The effect is not specific to salicylates, however, as 50 mM hydrocortisone (a much higher concentration than that seen in plasma after conventional doses) also abolished 125I-IFN γ binding (Fig 6).

Discussion
We have previously shown that the salicylates used in inflammatory bowel disease, their N-acetylated metabolites, and colchicine impair IFN γ induced colonic epithelial cell HLA-DR expression.\(^1\) We now show that this effect is also seen at the transcriptional level, that IFN γ binds to colonic epithelial cells, and that this binding is reduced in the presence of salicylates. This inhibition occurs at concentrations of 5ASA and N-acetyl 5ASA found in the rectal lumen of patients taking therapeutic doses of 5ASA containing compounds\(^4\) and is of the same magnitude as the reduction in IFN γ induced HLA-DR expression.

IFN γ is a pleiotropic cytokine released by T and natural killer (NK) lymphocytes and has similar antiviral, antitumour, and pyrogenic activity to the IFN αs and IFN β.\(^4\) IFN γ also has a wide range of immunomodulatory properties, including induction of class I and II histocompatibility antigens, Fc receptors, and adhesion molecules; activation of macrophages, T lymphocytes, and NK cells; stimulation of T and B lymphocyte proliferation; and differentiation.
and induction of their cytokines.\textsuperscript{18-20} IFN $\gamma$ has also been shown to increase permeability across colonic epithelial monolayers.\textsuperscript{21}

IFN $\gamma$ binds to a 95 kDa cell surface receptor which is present on most cell lines that have been tested and is distinct from the receptor mediating the actions of the IFN $\alpha$s and IFN $\beta$. Estimates of its $K_d$ have varied from $10^{-11}$ to $10^{-7} \text{ M}$ and the number of receptors/cell from 100 to 10 000.\textsuperscript{22} The mechanism of signal transduction after IFN $\gamma$ binding is unknown.

The mode of action of 5ASA and 4ASA in inflammatory bowel disease is unknown. A variety of mechanisms have been proposed, including inhibition of prostaglandins,\textsuperscript{23} leukotrienes,\textsuperscript{24} or platelet activating factor;\textsuperscript{25} free radical scavenging;\textsuperscript{26} inhibition of neutrophil, macrophage, or mast cell function;\textsuperscript{27} alteration of colonic permeability;\textsuperscript{28} inhibition of humoral immunity;\textsuperscript{29} impaired cytokine production;\textsuperscript{30} N-acetyl-5ASA is the major metabolite of 5ASA and the primary site of metabolism is probably the colonic mucosa.\textsuperscript{31} Two studies have failed to show any effect of N-acetyl-5ASA enemas in ulcerative colitis,\textsuperscript{32,33} although a third reported sigmoidoscopic and histological improvement.\textsuperscript{34} These findings are possibly explained by poor rectal absorption of N-acetyl-5ASA.\textsuperscript{35}

The data presented here suggest that these compounds may act by impairing the binding of IFN $\gamma$ to its receptor on the colonic epithelial cell. It is possible that they may also affect IFN $\gamma$ binding to other cells involved in the colonic mucosal immune response. Although olsalazine was the most potent inhibitor, in vivo measurements have shown that it is almost completely metabolised in the colonic lumen.\textsuperscript{36}

In contrast, the reduction of IFN $\gamma$ induced epithelial HLA-DR expression by colchicine is not caused by interference with receptor binding. It is more likely to be an intracellular effect of tubulin binding.

As IFN $\gamma$ has such a wide range of effects, an impaired ligand-receptor interaction would modulate the mucosal immune response by a number of mechanisms. Maintenance of low epithelial permeability, inhibition of antigen presentation by epithelial or subepithelial antigen presenting cells, and inhibition of activation or proliferation of immune effector cells could all contribute to the prevention or control of colonic mucosal inflammation.

Some of these data have previously been published in abstract form (Gastroenterology 1991; 100: A570).

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