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**Echinacea as an Antiinflammatory Agent: The Influence of Physiologically Relevant Parameters**

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Numerous Echinacea preparations are available on the market for the prevention and treatment of cold and ‘flu symptoms and inflammatory conditions associated with infections. Most of these preparations are consumed orally in the form of aqueous or ethanol extracts and tinctures. Since the recommended consumption normally involves a brief local exposure to the diluted preparation at an unspecified time in relation to the actual infection, then it is important that experimental models for the evaluation of Echinacea reflect these limitations. A line of human bronchial epithelial cells, in which rhinoviruses stimulate the production of pro-inflammatory cytokines, was used to evaluate several relevant parameters. The chemically characterized Echinacea preparation (Echinaforce®) was capable of inhibiting completely the rhinovirus induced secretion of IL-6 (interleukin-6) and IL-8 (chemokine CXCL-8) in these cells, regardless of whether the Echinacea was added before or after virus infection, and in response to a range of virus doses. This inhibitory effect was also manifest under conditions resembling normal consumption with respect to the duration of exposure to Echinacea and the Echinacea dilution. It is concluded that under real life conditions of Echinacea consumption, the virus-induced stimulation of pro-inflammatory cytokines can be effectively reversed or alleviated.

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**INTRODUCTION**

Different species and parts of Echinacea (Asteraceae) plants have been used traditionally in North America for the treatment of various symptoms of ‘colds’ and ‘flu’, as well as other applications (Barnes et al., 2005). A number of well known marker compounds have been characterized, including polysaccharides, specific caffeic acid derivatives and alkylamides (Bauer, 1998; Binns et al., 2002), and these have all demonstrated biological activities in various tests in vitro and in vivo (Bauer, 1998; Vimalanathan et al., 2005; Sharma et al., 2006; Woelkart and Bauer, 2007; Altamirano-Dimas et al., 2007). The variety of these bio-activities suggests that the interactions between Echinacea and cells are complex, and may involve different levels of action and different compounds.

Many clinical trials have been conducted in individuals suffering from natural or experimentally induced rhinovirus infections, but with variable results (Barnes et al., 2005; Schoop et al., 2006; Woelkart and Bauer, 2007; Shah et al., 2007). This variability may be due to differences in the therapeutic products and experimental protocols. Thus the question of clinical efficacy will remain unresolved until some of the variables have been considered systematically. There has also been considerable discussion about the timing of Echinacea consumption, in relation to cold or ‘flu symptoms, what kind of formulation should be consumed, and in what dosage. It should be possible to resolve most of these issues by judicious use of appropriate model systems.

Rhinoviruses have been implicated as major players in common colds and various types of allergic rhinitis and bronchial syndromes (Message and Johnston, 2004; Schaller et al., 2006). However, numerous studies have shown that rhinovirus infection in cultured epithelial cells, and in nasal epithelial tissues *in vivo*, results in relatively low levels of virus replication and cytopathology, apparently due to the small number of cells supporting virus replication (Gwaltney, 2002; Mosser et al., 2005), yet in spite of this there is substantial induction of secretion of certain pro-inflammatory cytokines and chemokines, particularly IL-6 and IL-8 (Message and Johnston, 2004, Sharma et al., 2006; Schaller et al., 2006; Edwards et al., 2007). Thus the typical symptoms of a common cold, such as sneezing, coughing, runny nose, stuffed nasal passages, etc. (Gwaltney, 2002), are not the direct result of viral pathology, but rather the indirect stimulation of pro-inflammatory cytokines and chemokines, which are secreted and attract the various inflammatory leukocytes to the site of infection. Consequently, the successful treatment of colds and ‘flu might be obtained by appropriate use of an antiinflammatory material. This can be evaluated in an experimental cell culture system, provided it bears resemblance to the *in vivo* situation.

To carry out such an analysis, the rhinovirus infected BEAS-2B epithelial cell system was used, together with a standardized and chemically characterized preparation of *Echinacea purpurea*, to evaluate the role of various experimental parameters relevant to a natural infection involving symptoms of the ‘common cold’.

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MATERIALS AND METHODS

**Echinacea** source. The test material was Echinacea purpurea (A. Vogel Bioforce AG, Switzerland), a 65% ethanol extract of freshly harvested aerial parts of *Echinacea purpurea* supplemented with 5% *E. purpurea* roots. This preparation was essentially free of polysaccharides, and contained the following caffeic acids and alkylamides (caffeic acid 0, caffeic acid 264.4 μg/mL, chlorogenic acid 40.2 μg/mL, cichoric acid 313.8 μg/mL, cyanarin 0, echinacoside 6.9 μg/mL, PID 8/9 36.3 μg/mL). The composition was determined (courtesy J. T. Arnason, University of Ottawa) by HPLC as described in Binns et al. (2002).

**Cells and viruses.** BEAS-2B human epithelial cells, originally obtained from ATCC, were grown in Dulbecco MEM (DMEM) in 10% fetal bovine serum. For the experiments, the cells were sub-cultured in 6-well trays, and when confluent the medium was changed to DMEM, HBSS (Hanks balanced salt solution), or PBS (phosphate buffered saline), without serum. Under these conditions the cultures remained viable for at least 5 days. The H-1 sub clone of HeLa cells (ATCC) and the human lung epithelial cell line A-549 (ATCC), were grown in Dulbecco MEM (DMEM) in 10% fetal bovine serum. For the experiments, the cells were sub-cultured in 6-well trays, and when confluent the medium was changed to DMEM, HBSS (Hanks balanced salt solution), or PBS (phosphate buffered saline), without serum. Under these conditions the cultures remained viable for at least 5 days. The H-1 sub clone of HeLa cells (ATCC) and the human lung epithelial cell line A-549 (ATCC), were grown in DMEM + 5% fetal bovine serum. Human skin fibroblasts (courtesy Dr Aziz Ghahtary) in their sixth passage were also cultivated in DMEM with 10% serum. No antibiotics or antimycotic agents were used.

Rhinovirus types 1A and 14 (RV 1A and RV 14, from ATCC) were propagated and assayed, by plaque assay, in H-1 cells. The stock viruses had titers of between $10^7$ and $10^8$ pfu/mL.

**Test system.** Details of the test system were described previously (Sharma et al., 2006). BEAS-2B cells, and other cells, were grown in complete medium, in 6-well trays, to produce confluent monolayers. The medium was then replaced with PBS (phosphate buffered saline) or other serum-free media for the experiments. Virus was added to the cells at a multiplicity of infection 1.0 infectious virus per cell (1 pfu/cell), unless noted otherwise, for 1 h at 35 °C, followed by a 1:100 dilution of Echinacea in PBS. Culture supernatants were harvested at the indicated times for measurement of cytokines, by ELISA tests.

ELISA assays were carried out according to the instructions supplied by the companies (either Immunotools, Germany, or e-Bioscience, USA).

RESULTS

**Kinetics of pro-inflammatory cytokine secretion in different media**

In order to establish a relevant, consistent and reliable culture system in which to evaluate antinflammatory activity, the study compared the kinetics of secretion of several cytokines in uninfected and RV-infected BEAS-2B cells in different media (MEM, the normal culture medium; HBSS, Hank’s balanced salt solution; PBS, phosphate buffered saline) over a period of several days. During this time the level of IL-6 and IL-8 secretion changed relatively little in uninfected cells, particularly in PBS or HBSS. Virus infection, however, resulted in substantial cytokine induction, first observed at 4 h after infection, but in greater amounts at 24–96 h, for both IL-6 and IL-8 (Figs 1 and 2). After this time the levels of cytokines declined.

Figure 1 shows the comparison between the relative amounts of IL-6 and IL-8 at 48 h after infection. Although the maximum amount of induced cytokine was usually somewhat higher in the presence of complete medium, the differential between control and virus infected cells was consistently larger in PBS and HBSS (data not shown). Therefore it was decided to use PBS for most of the subsequent experiments. In addition as simple a medium as possible was used to avoid possible interactions between medium and Echinacea components.

Figure 1 also shows the dramatic inhibitory effect of Echinacea on induced IL-6 and -8, which were often reduced to control levels. Similar results were obtained for any of the time points chosen, 24–96 h (not shown). However, there was no significant effect of Echinacea on the levels of these cytokines in control uninfected cells (Fig. 1).

These results were unaffected by the passage number of the BEAS-2B cells; passage 8 and passage 54 cells showed similar responses to RV infection and to Echinacea inhibition (not shown). In addition rhinovirus type 1A (RV 1A), which uses a different cellular receptor from RV 14 (LDL instead of ICAM-1), showed results similar to RV 14.

Furthermore similar results were obtained when the BEAS-2B cells were replaced by A549 human lung epithelial cells, or by human skin fibroblast cells (data not shown).

**Time of addition of the Echinacea**

Since the exact time of a natural rhinovirus infection can never be certain, or the interval between infection and
ECHINACEA AS AN INFLAMMATORY AGENT

Figure 2. Time course of RV-induced cytokines ± Echinacea. BEAS-2B cells were grown to confluent monolayers, and half the cultures were infected with RV 14 (1 pfu/cell) for 1 h. The media on both infected and uninfected cultures were then replaced with phosphate buffered saline with or without Echinacea at 1:100 dilution. Periodically, culture supernatants were removed for assay of IL-6 and IL-8. For simplicity only the values for RV-infected cultures are shown. RV14, infected cultures without Echinacea; RV14 + E, infected cultures plus Echinacea at 1:100 dilution.

One would reasonably expect greater amounts of virus to produce more intense symptoms. To test this increasing concentrations of virus (RV14) were used, from 0.01 to 1.0 pfu/cell, which resulted in successively greater amounts of cytokine induction, for both IL-6 and IL-8. For simplicity only the values for RV-infected cultures are shown. RV14, infected cultures without Echinacea; RV14 + E, infected cultures plus Echinacea at 1:100 dilution.

In the standard treatment (Fig. 1), Echinacea was added immediately after virus infection, and incubated for an additional 24–48 h. However, when the addition of Echinacea was delayed for 4, 24 or 48 h after virus infection, and the exposure to Echinacea continued for a further 24 h, the virus-induced cytokine induction was still inhibited (Fig. 2) for both cytokines. In addition Echinacea can also be added 24 h before infection, and still inhibit subsequent RV-induced stimulation of cytokines (see below).

Echinacea dose effect

A common question about Echinacea consumption is: how much is appropriate for its success in counteracting cold symptoms?

To determine if the inhibitory capacity of Echinacea was dose dependent, as might be expected, the anticytokine effect of different doses was examined, using the same experimental conditions described above. The previous tests (Fig. 1) utilized a 1:100 dilution of Echinacea, equivalent to a final concentration of 160 μg/mL. However inhibition was still observed with dilutions up to 1:400, and occasionally at 1:800, but there was clearly a dose response effect, as shown in Fig. 3. This suggests that the preparation could be diluted considerably and should still be active. None of the Echinacea doses used in these studies appeared to have adverse effects on the cells.

Effect of virus concentration (multiplicity of infection, MOI)

Another variable that could affect the outcome of a cold is the amount of virus acquired in the infection. One would reasonably expect greater amounts of virus to produce more intense symptoms.

To test this increasing concentrations of virus (RV14) were used, from 0.01 to 1.0 pfu/cell, which resulted in successively greater amounts of cytokine induction, for both IL-6 and IL-8 (Fig. 4), although even at a multiplicity of infection of 1.0 infectious virus per 100 cells there was still a substantial induction in cytokine secretion after 48 h. Nevertheless, in all cases Echinacea was able to reverse these responses and bring the cytokine levels down to the control levels previously indicated in Fig. 2. These data are shown for A-549 cells: but similar results were obtained for BEAS-2B cells.
Figure 4. Effect of virus concentration. A549 cells were grown to confluent monolayers, and half the cultures were infected with RV 14, at various multiplicities of infection, $10^{-2}$, $10^{-1}$ or 1.0 pfu/cell. After 48 h, supernatants were removed from all cultures for assay of IL-6 and IL-8. Data are shown only for infected cultures. Control values were all low (<200 pg/mL).

Figure 5. Duration of Echinacea exposure. BEAS-2B monolayers were produced as usual, and half the cultures were infected with RV 1A, 1 pfu/cell, followed by exposure of infected and uninfected cultures to Echinacea at 1:100 dilution for various times, followed by washing to remove excess Echinacea. All cultures were then incubated for the balance of the 48 h period, at which point supernatants were removed and assayed for IL-6 and IL-8. Data are shown only for the infected cultures; all the control values were very low (<200 pg/mL). RV 1A, virus only, no Echinacea; E5, E30, E1H, E48H, indicate times of exposure of infected cultures to Echinacea at 1:100 dilution.

Duration of exposure to Echinacea

In order to mimic the natural consumption of Echinacea, experiments were carried out in which Echinacea (at the usual 1:100 dilution) was added to the RV-infected cells for various times, and then the Echinacea washed off the cells. Cytokine secretion was then measured 24 h later. A short exposure of only 5 min did not significantly affect the RV-induction of cytokines; however, with increasing exposure to Echinacea, the more effective was the cytokine inhibition (Fig. 5). This suggests that under normal conditions of oral Echinacea consumption, inhibition of RV-induced cytokine secretion could be substantial, even with a high virus input.

Although the results presented in Fig. 5 indicate that a brief 5 min exposure to 1:100 Echinacea was not very effective, nevertheless the results in Table 1 show that a 5 min exposure to 1:10 Echinacea (a more realistic dose in practice) gave a significant reduction in IL-6.

### DISCUSSION

The present results show that Echinaforce, at a concentration resembling its natural consumption, is capable of completely reversing the rhinovirus induced secretion of the pro-inflammatory cytokines IL-6 and IL-8. These cytokines are prominent in numerous types of infection and inflammatory conditions (Message and Johnston, 2004; Schaller et al., 2006). In previous studies (Sharma et al., 2006) it was shown that other pro-inflammatory cytokines, which are induced to a lesser degree in the epithelial cells, e.g. SCF, were also inhibited by Echinacea preparations.

The degree of virus induced cytokine secretion was affected, as might be anticipated, by the amount of virus added to the cells, and this situation will reflect the natural variation in virus ‘doses’ that individuals receive during infection. It is unlikely, however, that a person would be exposed to more than 1.0 pfu/cell, the maximum dose used here, during normal exposure, especially since the yields of rhinoviruses in vivo are relatively low compared with other viruses (Gwaltney, 2002; Mosser et al., 2005). Therefore it is believed that the efficacy of Echinaforce described in this study is more than adequate to counteract the inflammatory response in normal rhinovirus infections.

Considerable dilution of the Echinaforce was still compatible with its efficacy; consequently the prescribed dosage of commercial preparations (at least for E. purpurea) is supported by these experiments.

A number of experiments were performed designed to mimic the natural uses of Echinacea, in terms of timing and duration of application. Echinaforce was still very effective when applied before, as well as up to 48 h after the virus infection, and the actual duration of exposure was not a limiting factor. Thus prophylactic and therapeutic usage is both supported. Therefore the recommendations for taking Echinacea preparations of this kind at the first sign of a cold are justified.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>IL-6 (pg/mL) (mean ± SEM)</th>
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<tr>
<td>RV infection for 48 h, no Echinacea</td>
<td>830 ± 3.4</td>
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<tr>
<td>RV infection followed by</td>
<td>64.7 ± 16.3</td>
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<tr>
<td>Echinacea 1:100 for 48 h</td>
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<tr>
<td>Pre-exposure to Echinacea 1:200</td>
<td>46.2 ± 2.2</td>
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<tr>
<td>for 24 h, followed by RV infection for 24 h</td>
<td></td>
</tr>
<tr>
<td>Pre-exposure to Echinacea 1:100 for 24 h</td>
<td>21.3 ± 1.3</td>
</tr>
<tr>
<td>followed by RV infection for 24 h</td>
<td></td>
</tr>
<tr>
<td>RV infection followed by Echinacea 1:10</td>
<td>588 ± 12</td>
</tr>
<tr>
<td>for 5 min, incubated for 24 h</td>
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</table>
The mechanisms of action of *Echinacea* are not understood, since previous studies (Barnes et al., 2005) have implicated possible roles for various constituents, such as polysaccharides, caffeic acid derivatives and alkylamides. *Echinaforce* is essentially free of polysaccharides, so they can be ruled out as major players in the cytokine effects, although it should be pointed out that *Echinacea* preparations enriched in polysaccharides do have profound effects on gene expression (Altamirano-Dimas et al., 2007). Some of the other constituents possess antiviral, antibacterial and other activities (Vimalanathan et al., 2005; Sharma et al., 2008), and consequently different compounds, including additional known constituents, may be involved in the overall mechanism of action.

**REFERENCES**


