Interactions of BCG with urothelial tumor cells in immunotherapy for superficial bladder cancer

Bevers, R.F.M.

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Summary

The study was initiated as an in vitro approach to the situation existing during intravesical bacillus Calmette-Guérin (BCG) instillation in patients with superficial bladder cancer. Cytokine secretion of a human bladder carcinoma cell line T24 treated with BCG was investigated. A 24-h treatment of T24 cells with BCG resulted in a tenfold higher secretion of interleukin-6 (IL-6) and tumor necrosis factor alpha (TNFα) when compared with T24 cells treated with Escherichia coli, Streptococcus faecalis or a cell wall preparation of Nocardia rubra (N-CWS). No secretion of IL-1β and IL-
2 was detected. Pre-exposing T24 cells to BCG for various periods of time indicated that a minimum exposure time of 0.5 - 1 h was required to upregulate IL-6 and TNFα production. Extending the BCG pre-exposure time to 2 and 3 h further increased the rate of cytokine production. No significant difference was found, however, between the rates of secretion initiated after a 2-h or 3-h pre-exposure period. The amounts of these cytokines secreted in the presence of BCG-conditioned medium did not differ significantly from the constitutively secreted amounts, excluding an effect of products possibly secreted by BCG on the upregulation of IL-6 and TNFα. In addition, upregulation of cytokine production appeared to be dependent on the concentration of BCG. The results suggest that cytokines may be produced by urothelial tumor cells after intravesical instillation in patients with superficial bladder cancer, which may play a role in the mode of action of BCG.

Introduction

Intravesical instillation of bacillus Calmette-Guérin (BCG) has been recognized as an effective treatment in patients with superficial bladder cancer [10,15]. However, the absence of a clinical response of a subpopulation of patients is not understood, explaining the interest in basic research concerning BCG-associated anti-tumor activity and the search for prognostic markers.

Although a great deal of information on the mode of action of BCG as an anti-tumor modality is still lacking, the majority of the available evidence indicates an immune-mediated reaction, associated with local production of cytokines [2-4,9,18,19,23]. Knowledge of the mechanism of interaction of BCG with the bladder wall that initiates the immunological reaction is inadequate [12,22]. Data on a possible direct interaction between BCG and normal urothelium and/or tumor cells are scarce [1,26].

It is generally assumed that after BCG instillation the major cellular sources of the cytokines detected in urine are macrophages and lymphocytes infiltrating the bladder wall [4]. However, cytokine determinations in urine reflect the response of the entire bladder and other cellular sources cannot be excluded. The release of interleukin-1 and -6 (IL-1, IL-6) and tumor necrosis factor alpha (TNFα) has been reported for a number of other cell types, such as polymorphonuclear granulocytes, fibroblasts, and endothelial and epithelial cells [6,13,25], and in vitro studies with bladder tumor cell lines have shown that these cells are capable of cytokine gene expression. The bladder tumor cell line 5637 synthesizes mRNAs encoding for various
cytokines under steady-state conditions [11]. The constitutive synthesis of B cell growth factor (BCGF), at present known as interleukin-6 (IL-6), has been observed for T24 cells [20]. In view of these observations, an investigation was initiated to study the possible effects of BCG on bladder tumor cells.

This report describes the effects on the production of various cytokines by T24, a human bladder carcinoma grown in vitro, of treatment with BCG and various other bacteria commonly known to induce cystitis. BCG appeared to upregulate the production of IL-6 and TNFα by T24 cells. The consequences of these observations are discussed in relation to the BCG-associated inflammatory and immune reactions.

Materials and methods

Cells and culture conditions

Stock cultures of the human bladder carcinoma cell line T24 [5] were cultured as monolayers in standard Dulbecco's modified Eagle's medium (DMEM) supplemented with 10% fetal calf serum, 100 IU/ml penicillin and 100 μg/ml streptomycin. Cells were grown at 37 °C in a humidified 10% CO₂ atmosphere at pH 7.4 until subconfluency. Cultures were screened for mycoplasma. For passage and experiments, cells were trypsinized with 0.05% trypsin and 0.02% EDTA in phosphate-buffered saline (PBS) consisting of 8 g NaCl, 0.2 g KCl, 1.16 g Na₂HPO₄ x 2H₂O and 0.2 g KH₂PO₄ per liter at pH 7.4. All tissue culture chemicals were obtained from Flow Laboratories (Irvine, UK). Tissue culture plastics were from Costar (Cambridge, Mass.).

Bacterial preparations

Escherichia coli and Streptococcus faecalis were grown according to standard microbiological procedures, washed and diluted to appropriate concentrations with DMEM. Freeze-dried BCG, strain Connaught, was reconstituted in 1.0 ml diluent consisting of 0.85% NaCl, 0.025% Tween, 0.06% NaH₂PO₄ and 0.25% Na₂HPo₄ and diluted to appropriate concentrations with DMEM. Five hundred micrograms Rubratin (N-CWS), a lyophilized cell wall skeleton preparation of Nocardia rubra with reported immunomodulating activity [7], was reconstituted in 1.0 ml saline and diluted with DMEM. For determination of the effects of the various bacteria and N-CWS on cytokine secretion, the bacteria or N-CWS were added to T24 cultures for various periods of time. Subsequently, the medium was collected, centrifuged and stored at -20 °C. The amounts of the various cytokines were determined within 2 months of collection.
Study design
A total of $3 \times 10^5$ T24 cells (2 cm$^2$; 1 ml medium) were treated according to the following protocols:

1. Cells were incubated continuously for 24 h with BCG as well as with several other bacteria at various concentrations. At the end of the 24-h period medium was collected for cytokine determinations.
2. Cells were pre-exposed to BCG ($2 \times 10^6$ cfu) for time intervals ranging from 0.25 to 3 h, washed 3 times with DMEM and fresh culture medium added. Subsequently samples of medium were taken regularly over a period of 8-12 h for cytokine determinations.

Determination of IL-6, IL-1β, IL-2 and TNFα
IL-1β, IL-2, IL-6, and TNFα were quantified with a human-specific, oligoclonal enzyme-linked immunosorbent assay (ELISA) obtained from Medgenix (Fleurus, Belgium). We recently demonstrated a significant relation between the Medgenix ELISA and the bioassay utilizing a variant (subclone 9.9) of the original IL-6 dependent hybridoma cell line B 13.29 as described by van Oers et al. [17,23].

Determination of total protein and the rate of protein synthesis
Proliferation of T24 cells during the experiments was determined by measuring total cellular protein [16,21]. Labeling and measurement of the rate of protein synthesis were performed as described by Schamhart et al. [24].

Statistical analysis
To test for differences between groups, series of one-way analyses of variance of equal or unequal size were used. When significant ($P<0.05$) differences were found by analysis of variance, Duncan's multiple range test [8] or, in the case of an unequal number of replications, Duncan's multiple range test as adjusted by Kramer, was performed ($P = 0.05$) [14].

Results

Bacteria-induced cytokine secretion by T24 cells
Initially, secretion of IL-6 and TNFα by T 24 cells was determined after a 24-h exposure to BCG Connaught, N-CWS, E. coli and S. faecalis at various concentrations (Table 1). The results showed a strong enhancement of IL-6
**Table 1.** IL-6 and TNFα secretion of T24 cells after 24 h of incubation with different bacteria and bacterial cell walls

<table>
<thead>
<tr>
<th>Incubated with</th>
<th>Quantity</th>
<th>IL-6 (ng)</th>
<th>TNF (pg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td></td>
<td>1.0 ± 0.6 (6)</td>
<td>9.5 ± 3.0 (6)</td>
</tr>
<tr>
<td>BCG Connaught</td>
<td>2 x 10⁵ cfu</td>
<td>2.1 ± 0.8 (4)</td>
<td>23.2 ± 3.6 (3)</td>
</tr>
<tr>
<td></td>
<td>2 x 10⁶ cfu</td>
<td>37.8 ± 1.6 (4)</td>
<td>136.0 ± 6.3 (3)</td>
</tr>
<tr>
<td></td>
<td>2 x 10⁷ cfu</td>
<td>22.9 ± 1.0 (3)</td>
<td>94.7 ± 7.0 (3)</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>1 x 10⁵ cfu</td>
<td>0.4 ± 0.1 (3)</td>
<td>9.9 ± 2.8 (3)</td>
</tr>
<tr>
<td></td>
<td>1 x 10⁶ cfu</td>
<td>2.0 ± 0.3 (3)</td>
<td>9.8 ± 0.1 (3)</td>
</tr>
<tr>
<td></td>
<td>1 x 10⁷ cfu</td>
<td>4.1 ± 0.0 (3)</td>
<td>7.6 ± 11.6 (3)</td>
</tr>
<tr>
<td><em>Streptococcus faecalis</em></td>
<td>2 x 10⁵ cfu</td>
<td>0.5 ± 0.0 (3)</td>
<td>1.0 ± 0.6 (3)</td>
</tr>
<tr>
<td></td>
<td>2 x 10⁶ cfu</td>
<td>0.4 ± 0.0 (3)</td>
<td>1.0 ± 0.1 (3)</td>
</tr>
<tr>
<td></td>
<td>2 x 10⁷ cfu</td>
<td>1.8 ± 0.5 (3)</td>
<td>1.0 ± 1.5 (3)</td>
</tr>
<tr>
<td>N-CWS</td>
<td>0.6 µg</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6.0 µg</td>
<td>0.7</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>60.0 µg</td>
<td>3.3</td>
<td>-</td>
</tr>
</tbody>
</table>

IL-6 = Interleukin-6; TNF = tumor necrosis factor; - = not determined

* 3 x 10⁵ T24 cells were incubated for 24 h in the presence of the indicated number of bacteria or bacterial cell walls (N-CWS)

* Mean ± SD (number of replications)

* P < 0.05 compared with constitutive secretion (“None”)

and TNFα secretion in the presence of BCG compared with the amounts produced constitutively or in the presence of the other bacteria investigated. The highest BCG-induced IL-6 and TNFα secretion was about 10 times higher than that induced by *E. coli, S. faecalis* or N-CWS. In addition, the induction of IL-6 and TNFα appeared to be concentration dependent. No proliferation or lysis of T24 cells was observed during the time course of the experiments. Under these conditions no bacteria-induced IL-1β or IL-2 was detected.
Production of IL-6 and TNFα after BCG pre-exposure for various periods of time

In a next series of experiments the effects of pre-exposure of T 24 cells to BCG (2 x 10^6 cfu) for 0, 0.25, 0.5, 1, 2, and 3 h on IL-6 and TNFα production were studied (Fig. 1). Subsequent monitoring over a period of at least 8 h after pre-exposure indicated that a minimum pre-exposure period of 0.5 - 1 h was required to upregulate cytokine production to a significant (P<0.05) degree. Increasing the pre-exposure time to 2 or 3 h resulted in an increase of the initial rate of IL-6 and TNFα production by a factor 2.9 ± 0.7 and 4.8 ± 2.0 respectively compared with a 1-h pre-exposure period. No
significant (P < 0.05) differences between 2-h and 3-h pre-exposures to BCG were found in the kinetics of IL-6 or TNFα production. Determination of the total rate of protein synthesis of T24 cells pre-exposed to BCG for 3 h showed that BCG did not affect the total rate of protein synthesis compared with that in untreated T24 cells (results not shown). These results establish that the upregulation of IL-6 and TNFα production by BCG did not result from an increase in the rate of total protein synthesis.

**Bacteria-secreted products and T24-cytokine secretion**

In order to investigate whether the observed cytokine secretion resulted from products secreted by the bacteria, T24 cells were incubated with BCG-conditioned (4 and 24 h) medium and the secretion of IL-6 and TNFα monitored over a period of 12 and 8 h, respectively (Fig. 1). No significant (P > 0.05) differences in cytokine secretion were found compared with their constitutive production. In contrast, incubating T24 cells with _E. coli_-conditioned medium for 24 h resulted in an IL-6 production (4.1 ± 0.1 pg) identical to that during incubation with 1 x 10⁹ cfu _E. coli_ (4.1 ± 0.0 pg), indicating the involvement of products secreted by _E. coli_ in the (slight) upregulation of IL-6.

**Discussion**

This study has demonstrated that, in contrast to various other bacteria, _bacillus Calmette-Guérin_ upregulates the production of IL-6 and TNFα, but not of IL-1β or IL-2, by the human bladder carcinoma cell line T24. The upregulation appeared to depend on both the concentration of BCG and the pre-exposure time to BCG. It should be noted that extrapolation of the data on cytokine production after pre-exposing T24 cells for 2 or 3 h to BCG results in a theoretical amount of approximately 2 ng IL-6 and 250 pg TNFα over a period of 24 h (Fig. 1), whereas after continuous incubation for 24 h with BCG total amounts of 37 ng IL-6 and 136 pg TNFα were observed (Table 1). Although not the immediate subject of this paper, the discrepancy between these figures, in particular of IL-6 production, may most probably be explained by a progressive increase in the rate of IL-6 synthesis during continuous incubation with BCG.

The pre-exposure period to BCG of 2-3 h required to obtain appreciable secretion of IL-6 and TNFα seems to agree with the reported time-dependent internalization of BCG by the bladder tumor cell lines T24 and MBT-2, which show a maximum at 3 h [1]. However, the current data do not exclude
BCG-induced upregulation of IL-6 and TNFα production by other, as yet unidentified mechanism(s) not related to internalization of BCG. Of these alternative mechanisms, upregulation of IL-6 by product(s) secreted by BCG into the medium has been excluded in the present study. Additional studies, including inhibition of the phagocytic process and the use of non-phagocytosing bladder (tumor) cell lines, are in progress to determine whether or not internalization is a prerequisite for upregulation of cytokine production. The absence of an effect of BCG on the rate of total protein synthesis and cell lysis and the absence of proliferation of T24 cells during the course of the experiments suggest a specific upregulation of de novo IL-6 and TNFα synthesis. As currently understood, BCG-mediated anti-tumor activity in humans results from stimulation of local immunological reactions [2,4,6,9,18,19,23,26] initiated by the attachment of BCG to the bladder. However, no conclusive data are available on this latter event [12,19,22]. Becich et al. [1] have suggested a potential active role of transitional epithelial cells (after BCG internalization) in the anti-tumor process. The present data, showing both a concentration dependency and the requirement for an exposure period of at least 2 h to obtain significant cytokine secretion by T24 cells, correlate with clinical observations and animal studies on BCG concentration dependency and the general clinical practice of retaining BCG in the bladder for 2 h. Furthermore, the specificity of BCG, compared with that of several other bacteria, in upregulating cytokine production by T24 cells seems to agree with clinical observations showing an increase in urinary cytokines after BCG instillation [3,23] and no significant increase in urinary cytokines in patients with urinary tract infections [4,9,un-published observations].

It is generally assumed that urinary cytokines found after intravesical BCG instillation are produced by leukocytes. From the present data it is tempting to speculate that cytokines may also be produced by tumor cells and/or normal urothelial cells as a result of their interaction with BCG. This phenomenon may be of additional importance in the BCG-associated immune response. However, further studies, including experiments using additional bladder cell lines with a different degree of differentiation, are needed to verify this hypothesis.

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References

8. Duncan DB (1955) Multiple range and multiple F tests. Biometrics 11:1