Cytotoxic Effects of Ad5CMV-p53 Expression in Two Human Nasopharyngeal Carcinoma Cell Lines

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ABSTRACT

Nasopharyngeal carcinoma (NPC) is a malignant disease of the head/neck region with a 5-year survival level of approximately 65%. To explore novel therapeutic strategies in the management of this disease, the potential of Ad5CMV-p53-mediated gene transfer to NPC cells was investigated in vitro. Two NPC cell lines, CNE-1 and CNE-2Z, were infected with either Ad5CMV-p53 or Ad5CMV-β-galactosidase and evaluated for transduction efficiency and transgene expression and were resistant to Ad5CMV-p53-mediated cytotoxicity. These data demonstrate the efficacy of Ad5CMV-p53-mediated gene therapy in human NPC, thus warranting additional investigations of this therapeutic strategy.

INTRODUCTION

NPC is a malignant disease of the head/neck region that is endemic in Southeast Asia and has an annual incidence of up to 25-50/106. It affects predominantly a young population, with the median incidence age in the fourth decade (1). Currently, the only proven curative modality is ionizing radiation, but the 5-year overall survival is still only around 65% (1, 2). This is clearly a disease site whereby novel experimental therapeutic strategies need to be developed. Recent reports have demonstrated that expression of a wild-type p53 gene from an adenovirus vector results in significant toxicity in a number of human tumor cell lines and xenografts (3-10). Hence, this prompted us to examine the potential of this therapeutic strategy for NPC.

There is currently controversy with regard to p53 status in human NPC. The majority of reports indicate that the p53 gene is not mutated in the primary tumor but is more likely to be mutated in metastases and derived cell lines (11-15). However, two recent reports that examined p53 expression using immunohistochemical techniques indicate that the majority of human NPCs overexpress the p53 protein (16, 17). The etiology of NPC remains to be elucidated, but there is the almost constant association with EBV, whose protein products have been demonstrated to bind p53 (18-20). The functional significance of this protein binding is not clear but might in part account for the conflicting observations with regard to p53 in human NPC. Introduction of a recombinant human wild-type p53 gene using the adenovirus route seems to be most toxic in tumors with null or mutated p53 (3-7, 9, 10), but in some cases, has also been shown to be cytotoxic in tumors expressing wild-type p53 (5-7).

One of the major difficulties in the clinical application of gene therapy in cancer treatment is efficient delivery of the vector-gene product to the tumor site. The nasopharynx can potentially be amenable to the introduction of exogenous gene products through either an aerosol route or direct infiltration. The reality of these theoretical advantages remains to be proven in progressively more complex models in the laboratory; the first step, however, is to demonstrate that this strategy is cytotoxic to NPC cell lines in vitro.

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The abbreviations used are: NPC, nasopharyngeal carcinoma; FBS, fetal bovine serum; pfu, plaque-forming unit; CMV, cytomegalovirus; MTT, 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide; MOI, multiplicity of infection; mAb, monoclonal antibody; AO, acridine orange; EB, ethidium bromide.
MATERIALS AND METHODS

Cells and Culture Conditions. The NPC cell lines CNE-1 (21) and CNE-2Z (22) were obtained from the Cancer Institute/Chinese Academy of Medical Sciences in China. Both cell lines have identical mutations in the p53 gene within exon 8, resulting in a change in the nucleotide sequence from AGA to ACA at codon 280 (12, 13). The adenovirus was propagated in the human embryonic kidney cell line 293 (American Type Culture Collection); purity of adenovirus was tested using the HeLa cell line (American Type Culture Collection). All cell lines were maintained in α-MEM supplemented with 10% FBS (Wisent, Inc., Quebec, Canada). GM38, a human fibroblast cell strain derived from a healthy 9-year-old female skin explant (Ref. 23; kindly supplied by Dr. Mike Rauth at Ontario Cancer Institute), was maintained in α-MEM supplemented with 15% FBS. All experiments were conducted when the cells were in an exponential growth phase.

Recombinant Adenovirus Vector. The adenovirus vector was obtained from Dr. Frank Graham at McMaster University (Hamilton, Canada). The Ad5CMV-p53 is a replication-deficient adenovirus vector containing a CMV promoter and a recombinant human wild-type p53 gene. Control adenovirus vector used in this study was Ad5CMV-β-galactosidase, an adenovirus vector containing the β-galactosidase gene. A single clone of the adenovirus vector was prepared by plaque purification and amplified in 293 packaging cells. The 293 cells were harvested 2 days after infection and purified using a modified protocol (24). Briefly, cells were suspended in 0.1 M Tris buffer (pH 8.0), 0.1 volume of 5% sodium deoxycholate solution was added, and the cell suspension was left on ice for 30 min. The virus was released with 3 cycles of 30-s sonication with a sonicator (Conics & Materials, Inc., Danbury, CT). Each 3.1 ml of the supernatant were mixed with 1.8 ml of saturated CsCl (Sigma Chemical Co., St. Louis, MO), transferred to Ti-50 ultraclear quick-seal tubes, and spun in a Ti-50 rotor at 35,000 rpm for 20 h at 15°C in an ultracentrifuge (Beckman LB-70M). The viral bands were collected and dialyzed against 0.01 M Tris buffer (pH 8.0) overnight at 4°C, with two changes of the dialysis buffer. The dialyate was aliquoted and stored in PBS, fixed with 2% formaldehyde and 0.2% glutaraldehyde for 5 min at 4°C, and stained for β-galactosidase. Blue staining in cells indicated expression of β-galactosidase; infection efficiency was evaluated by the ratio of the number of positively and negatively stained cells.

Western Blot Analysis of p53, WAF1/CIP1, bcl-2, and bax Proteins. Cells (5 × 10^5) were plated in T-25 flasks (Falcon, Franklin Lakes, NJ) and infected with Ad5CMV-p53/Ad5CMV-β-galactosidase ranging from 1–50 pfu/cell as described above. At each time point after infection (4, 8, 24, and 48 h), cells were harvested on ice, washed three times with PBS, and lysed in a lysis buffer (0.1 M Tris-Cl (pH 8.0), 1% SDS, 10 mM EDTA, and 2 mM DTT). The cell lysate was homogenized by 10 cycles of aspiration/expiration using a 1-ml syringe with a 21-gauge needle, then boiled for 2 min, and centrifuged at 14,000 rpm for 2 min (Eppendorf centrifuge; Brinkmann Instruments, Inc.). The protein concentration in the supernatant was determined using a bicinechonic acid protein assay kit (Pierce, Rockford, IL). Samples containing 30 μg of protein were denatured by boiling (for 5 min) in loading buffer (20% glycerol, 5% β-mercaptoethanol, 4% SDS, 125 mM Tris (pH 6.8), and 0.1 mg of bromphenol blue) and then electrophoresed on a 10% SDS-PAGE for 120 min at 100 V (Bio-Rad, Richmond, CA). The protein was transferred onto a nitrocellulose membrane using a trans-blot semi-dry cell (Bio-Rad). The membrane was blocked using PBST (0.1% Tween 20 in PBS) containing 5% low-fat milk for 60 min at room temperature and probed with the primary antibodies as follows: 1 μg/ml mAb for p53 (Ab-6; Oncogene Science); 1 μg/ml mAb for WAF1/CIP1 (Ab-1; Oncogene Science); 1 μg/ml mAb for bcl-2 (Ab 124; DAKO, Glostrup, Denmark); 1 μg/ml mAb for bax (Ab 4F11; Immunotech, France) in PBST with 5% low-fat milk. The blot was then washed with PBST and incubated with horseradish peroxidase conjugated to a secondary antibody. The specific complexes were detected by the chemiluminescence reagent (DuPont New England Nuclear, Boston, MA), and relative levels of p53, WAF1/CIP1, bcl-2, and bax proteins were evaluated using a computerized densitometer scanner (Molecular Dynamics, Sunnyvale, CA).

Effect of Ad5CMV-p53 on Cell Growth. To evaluate the effect of the adenovirus vector on cell growth, 1 × 10^5 cells were seeded onto 6-well plates (Nunc, Inc.). After 24 h, cultures were infected with either Ad5CMV-p53 or Ad5CMV-β-galactosidase at various MOI (1, 10, 25, and 50 pfu/cell) in 0.5 ml of medium containing 2% FBS at 37°C for 1 h. Subsequently, 3.5 ml of medium with 10% FBS were added to each well, and the infected cultures were incubated for 3 h. Cells were then trypsinized and plated onto 96-well plates (Nunc, Inc.) at cell densities of 1.5 × 10^3/well for CNE-1 and CNE-2Z cells and...
ene blue in 50% ethanol, and the number of colonies in each cells/dish. The dishes were then incubated in a 37°C/S%CO₂ incubator for 7-10 days. Staining was conducted using methylene blue in 50% ethanol, and the number of colonies in each stained dish was subsequently counted.

Clonogenic survival was assayed at the same time by reseeding the cells onto 100-mm dishes at a density of 10²–10⁴ cells/dish. The dishes were then incubated in a 37°C/5% CO₂ incubator for 7-10 days. Staining was conducted using methylene blue in 50% ethanol, and the number of colonies in each stained dish was subsequently counted.

DNA Fragmentation Analysis. After infection with Ad5CMV-p53 or Ad5CMV-β-galactosidase at various time intervals, cells were harvested and washed with PBS. The cell pellets were resuspended in 200 μl of 5 M guanidium containing 0.1 M 2-mercaptoethanol and 100 μl of 7.5 M ammonium acetate, followed by 600 μl of 100% ethanol. The samples were then placed on ice for at least 2 h. DNA was precipitated by centrifugation at 14,000 rpm for 30 min (4°C) in the Eppendorf centrifuge and washed twice using 75% ethanol. DNA extracts were dissolved in Tris-EDTA buffer (10 mM Tris, 1 mM EDTA (pH 8.0)) and subjected to electrophoresis on a 2% agarose gel; DNA bands were visualized using EB staining.

Morphological Assessment of Apoptosis. Apoptosis was also evaluated morphologically using (AO (Sigma)-EB (Sigma) fluorescence staining (30). Cells were washed with PBS, pelleted gently, resuspended in 1 ml PBS, and then mixed with 20 μl of AO-EB stock for a final concentration of 2.5 μM. The stained cells were centrifuged to remove the supernatant and resuspended in 30 μl of 10% glycerol in PBS. The cells were then placed onto glass slides and immediately visualized using a fluorescent microscope (Leica).

RESULTS

Ad5CMV-p53 and Ad5CMV-β-galactosidase Vectors. To ensure that the adenovirus vector was incapable of replication in nonpermissive cells, consecutive infection tests were performed by treating HeLa cells with the purified adenovirus vector. The second and the third sets of HeLa cell cultures were infected by the first and second sets of infected cell extracts, respectively. No cytopathic effect was observed in the second and third rounds of tested HeLa cell cultures. PCR analysis indicated that the purified Ad5CMV-p53 contained p53 cDNA but was devoid of E1 sequences, and no viral DNA was detected after the first round of Ad5CMV-p53 infection. In contrast, in the wild-type adenovirus-infected group, viral DNA replication was detected in all three rounds of HeLa cell cultures, and PCR also detected the E1 sequences (data not shown). Plaque assay

Fig. 1 X-galactosidase staining for β-galactosidase expression in Ad5CMV-β-galactosidase infection in CNE-1, CNE-2Z, and GM38 cells. Cells were exposed to either 50 pfu/cell of Ad5CMV-β-galactosidase or medium alone for 48 h. A, CNE-1 control; B, CNE-1 + Ad5CMV-β-galactosidase (50 pfu/cell); C, CNE-2Z control; D, CNE-2Z + Ad5CMV-β-galactosidase (50 pfu/cell); E, GM38 control; F, GM38 + Ad5CMV-β-galactosidase (50 pfu/cell).
Table 1  Summary of the transgene expressions and cytotoxic effects of Ad5CMV-p53 and Ad5CMV-β-galactosidase infections in each cell line

<table>
<thead>
<tr>
<th></th>
<th>CNE-1</th>
<th>CNE-2Z</th>
<th>GM38</th>
</tr>
</thead>
<tbody>
<tr>
<td>% β-galactosidase expression (intensity) (50 pfu/cell)</td>
<td>100% (+++)</td>
<td>&gt;90% (+++)</td>
<td>50% (+)</td>
</tr>
<tr>
<td>Fold induction of p53 protein (50 pfu/cell Adv-p53, 24 h)</td>
<td>800</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Fold induction of WAF1/CIP1 (50 pfu/cell Adv-p53, 24 h)</td>
<td>30</td>
<td>115</td>
<td>Not done</td>
</tr>
<tr>
<td>Fold induction of bcl-2 protein (50 pfu/cell Adv-p53, 24 h)</td>
<td>1</td>
<td>1</td>
<td>Not done</td>
</tr>
<tr>
<td>Fold induction of bax protein (50 pfu/cell Adv-p53, 24 h)</td>
<td>1</td>
<td>1</td>
<td>Not done</td>
</tr>
<tr>
<td>Growth inhibition (MTT) (50 pfu/cell Adv-p53, 5 days)</td>
<td>100%</td>
<td>90%</td>
<td>30%</td>
</tr>
<tr>
<td>Clonogenic survival (25 pfu/cell Adv-p53)</td>
<td>0.35%</td>
<td>11%</td>
<td>65%</td>
</tr>
<tr>
<td>DNA fragmentation (50 pfu/cell Adv-p53)</td>
<td>24 h</td>
<td>48 h</td>
<td>Not detected</td>
</tr>
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</table>

*Adv, adenovirus.

Fig. 2 Western blot analysis of Ad5CMV-p53-mediated protein expressions in CNE-1, CNE-2Z, and GM38 cells. Cells were infected with Ad5CMV-p53 at MOIs of 1, 10, and 50 pfu/cell for 4, 8, 24, and 48 h. For each group, 30 μg of cell lysate were separated on a 10% SDS-PAGE, electroblotted onto nitrocellulose membrane, and probed with the respective mAbs. Expression was detected using the enhanced chemiluminescence method. A, p53 and WAF1/CIP1; B, bcl-2 and bax expression.

demonstrated that the range of titers of the purified viral vectors was between 10^9–10^10 pfu/ml.

Ad5CMV-β-galactosidase-mediated Expression of β-galactosidase. To examine the infection efficiency and transgene expression of the adenovirus vector in CNE-1, CNE-2Z, and GM38 cells, β-galactosidase activity was assessed in cells infected with Ad5CMV-β-galactosidase. As demonstrated in Fig. 1, all three cell lines stained positively; the proportion of stained cells correlated with MOI in the range of 0.1–50 pfu/cell of Ad5CMV-β-galactosidase (data not shown). However, the proportion of stained cells differed between cell lines infected with the same dose of Ad5CMV-β-galactosidase. Positive staining was detected in both CNE-1 and CNE-2Z cells at 0.1 pfu/cell of Ad5CMV-β-galactosidase infection. At 25 pfu/cell of Ad5CMV-β-galactosidase, more than 90% of CNE-1 cells demonstrated positive X-galactosidase staining. However, 50 pfu/cell of Ad5CMV-β-galactosidase were required to infect CNE-2Z cells to the same level. In contrast, positively stained GM38 cells were first observed at a MOI of Ad5CMV-β-galactosidase of 1 pfu/cell and reached 50% at 50 pfu/cell of Ad5CMV-β-galactosidase. The intensity of X-galactosidase staining was greater in NPC cells as compared to GM38 fibroblasts, with CNE-1 cells displaying the most intense staining (Fig. 1; Table 1). No positively stained cells were observed in mock-infected cultures.

Ad5CMV-p53-mediated p53 Expression. To investigate the extent that Ad5CMV-p53 can mediate expression of a p53 minigene in infected cells, each cell line was exposed to a series of MOI of Ad5CMV-p53 or Ad5CMV-β-galactosidase for 4, 8, 24, and 48 h, and p53 protein expression was analyzed
p53 was sufficient to induce a significant increase in WAF1/galactosidase at fibroblasts at the 48-h time point, although note that only 50% baseline, but infection with either AdSCMV43-galactosidase demonstrated minimally detectable levels of bcl-2 and bax at 0% of p53, were analyzed using Western blotting. Specifically, we cytotoxicity of Ad5CMV-p53 infection on NPC cells, expression in cells infected at SO pfu/cell was lower for both dose-dependent increase in WAF1/CIP1 expression was observed in both NPC cell lines (Fig. 14). A induction in recombinant p53 expression was observed in GM38 cells were apparently infected with AdSCMV-p53; 1 pfu/cell of AdSCMV-p53 did not demonstrate p53 induction.

Effect of Ad5CMV-p53 on NPC Cell Growth. The cytotoxic effects of Ad5CMV-p53 on NPC cells were assessed using MTT and clonogenic assays. As shown in Fig. 3, infection of NPC cells with Ad5CMV-p53 from 1–50 pfu/cell resulted in a dose-dependent inhibition of cell growth in both NPC cell lines. When exposed to 50 pfu/cell of Ad5CMV-p53, complete inhibition of cell growth was observed in the CNE-1 cells, and 90% inhibition was observed in CNE-2Z cells at 5 days postinfection (Fig. 3A and B). In contrast, GM38 fibroblasts were resistant to the cytotoxic effects of Ad5CMV-p53 because more than 70% of cells continued to proliferate 5 days after treatment with 50 pfu/cell of Ad5CMV-p53 (Fig. 3C). Cells treated with Ad5CMV-β-galactosidase (50 pfu/cell) displayed little effect on growth (Fig. 3).

Fig. 3 Effect of Ad5CMV-p53 on cell growth. Cells were infected with Ad5CMV-p53 at MOIs of 1, 10, 25, and 50 pfu/cell or Ad5CMV-β-galactosidase at 50 pfu/cell. Culture medium was used as mock infections. Cells were seeded in quadruplicate in 96-well plates. Cell proliferation was analyzed by using the MTT assay on each day after infection, until day 5. Each data point represents the mean ± SE from three separate experiments. A, CNE-1 cells; B, CNE-2Z cells; C, GM38 cells, in which the Y axis has been magnified to facilitate data interpretation.
infected controls, cells treated with Ad5CMV-β-galactosidase, or GM38 fibroblasts (data not shown).

Morphological Analysis of Apoptosis. Morphological changes characteristic of apoptosis were investigated using AO-EB fluorescence staining after Ad5CMV-p53 or Ad5CMV-β-galactosidase treatment. The hallmarks of apoptosis, including chromatin condensation, loss of the nuclear envelope, and cellular fragmentation into apoptotic bodies were observed in both NPC cells 2 days postinfection with Ad5CMV-p53 at 50 pfu/cell (Fig. 6, E and F). No morphological changes were observed in mock-infected NPC cells or cells treated with Ad5CMV-β-galactosidase (Fig. 6, A–D).

DISCUSSION
In this study, we demonstrated that Ad5CMV-p53 was effectively cytotoxic against two human NPC cell lines. Infection with Ad5CMV-p53 resulted in high levels of recombinant p53 expression (and WAF1/CIP1), leading to cell death mediated through an apoptotic pathway. These data are similar to those of other groups that have tested this strategy in a myriad of human cancer cell lines, including melanoma (8), head/neck squamous cell (5, 7), breast (6, 10), ovarian (4), colorectal (3), and prostate cancers (9). The consistent observation is that recombinant p53 expression is increased after infection, and apoptosis seems to be responsible for the cytotoxicity. However, our data do raise some novel observations with regard to specific aspects of this gene therapy strategy.

The precise mechanisms of Ad5CMV-p53-mediated cytotoxicity are not well understood. It is known that p53 is involved in regulation of apoptosis and that an increase in its level can propel cells down an apoptotic pathway (31). It is logical that this technique of reconstituting normal p53 function in cancer cells with mutated p53 would be effective, and this has been demonstrated in a number of situations (4–7, 9, 10). Interestingly, however, this technique also seems to be effective against human cancer cell lines or tumors that express wild-type p53, although this seems to be less effective when compared to cells or tumors with null or mutated p53 (5–7). Why this strategy is cytotoxic to cells expressing wild-type p53 is not clear, but this underscores the complexity of the mechanisms involved in Ad5CMV-p53-mediated cytotoxicity.

Our data illustrated that even in two human cancer cell lines with the same histological origin (NPC) and with identical p53 mutations (12), infection with Ad5CMV-p53 resulted in a 30-fold difference in cytotoxicity (Fig. 4 and Table 1). We have tested the sensitivity of these two NPC cell lines after exposure to three cytotoxic modalities: ionizing radiation, heat, and Cisplatinum, and found no significant differences between them, with the exception that CNE-1 seems to be slightly more sensitive to each cytotoxic maneuver as compared to CNE-2Z cells.4 We have preliminary data suggesting that differences in infection efficiency between the two NPC cell lines may account for the variation in cytotoxicity, although the reason for the difference in incorporation efficiency currently eludes us.

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4 Unpublished observations.
Our study demonstrated that AdSCMV-p53 infection in NPC cell lines resulted in an increase in recombinant p53 expression, which in turn induced WAF1/CIP1 production. The one group that has published data on WAF1/CIP1 expression after AdSCMV-p53 infection did not conduct any kinetics experiments (6). We demonstrate that there is a time- and dose-dependent response in WAF1/CIP1 expression after introduction of the Ad5CMV-p53 gene, but by 48 h postinfection with Ad5CMV-p53 (50 pfu/cell), there was a significant decline in WAF1/CIP1 levels, particularly in the more sensitive CNE-l cells. We do not have a clear explanation for this observation. However, it was evident that by 48 h, the majority of CNE-l cells have lifted off the dish, DNA fragmentation was at its highest intensity (Fig. 5), and <1% of the cells displayed clonogenic potential (Fig. 4). In other words, most of the cells have died, so that presumably the machinery required to manufacture WAF1/CIP1 was no longer functioning and may therefore account for the decline in WAF1/CIP1 levels.

In an attempt to obtain some understanding of the complex mechanisms of Ad5CMV-p53-mediated cytotoxicity in the two NPC cell lines, we also evaluated the relative expression of bcl-2 and bax. These two gene products belong to the bcl-2 family, which has been implicated as mediators of p53-induced apoptosis, in that the ratio of bcl-2:bax can apparently influence the likelihood of cells to undergo apoptosis (32). Excess bax will promote apoptosis; excess bcl-2 can inhibit apoptosis. Our results demonstrated that Ad5CMV-p53 infection did not alter either bcl-2 or bax expression, indicating that neither protein seems to be an important mediator of apoptosis for the NPC cell lines in this study.

A number of groups have noted a differential sensitivity with this strategy in that there seems to be preferential cytotoxicity to cancer cells, with relative sparing of normal cells (6, 7, 10). Our data demonstrated that there was up to 200-fold greater resistance (Table 1 and Fig. 4) when the cells were treated with Ad5CMV-p53 at 25 pfu/cell between the NPC cells and the GM38 fibroblasts. The mechanisms behind the sparing of cytotoxicity of normal cells are also not known, but we suggest that viral incorporation efficiency may in part account for this difference. When we evaluated β-galactosidase expression by X-galactosidase staining (Fig. 1 and Table 1), it was evident that the least staining was observed in the GM38 fibroblasts; the most intense staining occurred with the CNE-l cells, with slightly less intense staining seen in the CNE-2Z cells. Viral incorporation efficiency, however, likely does not explain the entire picture because there is a 200-fold difference in cytotoxicity between the GM38 and CNE-l cells, but there is not that degree of difference in X-galactosidase staining intensity between the cells. Seth et al. have estimated the number of adenoviral receptors using 35S labeling and observed undetectable activity in human donor bone marrow cells as opposed to very high receptor numbers in several human breast cancer cell lines (10). The same group, in another report, evaluated β-galactosidase activity using a calorimetric assay but found no correlation between β-galactosidase activity and sensitivity to Ad5CMV-p53 infection (6). Clayman et al. (7) demonstrated that F138 human fibroblasts infected with AdSCMV-p53 did not demonstrate growth inhibition despite recombinant p53 expression (assayed using Western blot), but their blot suggested that recombi-
nent p53 protein level in F138 fibroblasts was less than that of the human squamous cell carcinoma cell line Tu-138. This suggests the possibility that viral incorporation efficiency may be lower in the fibroblasts compared to the cancer cell line (7).

The relevance of this therapeutic strategy to treatment of NPC in human patients remains to be determined. As stated earlier, p53 gene mutations seem to be relatively rare in human NPC (11–15), whereas p53 gene mutations in the in vitro model are 50% of the NPC cases (16, 17). What is clear, however, is the ubiquitous association of EBV with NPC (33). It is known that EBV-encoded proteins (BZLF1; EBNA-5) can bind to p53 in vitro (18–20), although the functional significance of this association is currently unclear. The NPC cell lines that we have studied in this current work have shed their EBV, hence, verification of the potential clinical application of this strategy would require the demonstration, in progressively more complex experimental models, that NPC tumors with retained EBV are sensitive to the cytotoxic effects of this therapeutic maneuver.

REFERENCES


Cytotoxic effects of Ad5CMV-p53 expression in two human nasopharyngeal carcinoma cell lines.

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