Regulation of Varicella-Zoster Virus Gene Expression in Human T Lymphocytes

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Varicella-zoster virus (VZV), a neurotropic alphaherpesvirus, is the etiologic agent of chicken pox and shingles (zoster) in humans. Primary VZV infection results in chicken pox and is usually characterized by a self-limiting generalized exanthema that is highly contagious and commonly seen in children. Following primary chicken pox infection, the virus remains latent in dorsal or cranial root ganglia. In elderly or immunocompromised individuals, the reactivation of latent virus leads to shingles, a condition with painful vesicular lesions usually limited to a single dermatome.

VZV is an enveloped virus with a linear double-stranded DNA genome of approximately 125,000 bp and a base composition of 46% guanine plus cytosine (G+C). The complete nucleotide sequence of the VZV genome has been determined and predicts approximately 70 unique genes (7). By analogy to related sequences in herpes simplex virus (HSV) and by direct analyses, functions have been assigned to many of the viral gene products, although the majority of these still remain undefined (24, 29, 35). Much progress has been made in functional analysis of HSV genes by generating specific mutations in the viral genome by exploiting its ability to undergo efficient homologous recombination (34). However, this approach has not been very fruitful in the study of VZV genes, since VZV has proven to be refractory to such genetic manipulations.

Although the expression of VZV genes appears to be temporally regulated (37), the inability to generate cell-free stocks of the highly cell-associated VZV with high titers has impeded the detailed analysis of VZV gene regulation. Nonetheless, putative kinetic classes have been defined for VZV genes on the basis of sequence homology and genetic topology to immediate-early (IE) (α), early (β), and late (γ) genes encoded by HSV type 1 (HSV-1) (5, 16, 17). Three putative VZV IE genes which correspond to ICP0, ICP4, and ICP27 in the HSV system have been identified. These are open reading frames (ORFs) 61, 62, and 4, respectively (6, 7, 37). Although complementation studies of HSV ICP4 mutants with VZV ORF62 have confirmed functional similarities between these two proteins, there is at present no evidence to indicate any functional similarities between either VZV ORF61 and ICP0 or VZV ORF4 and ICP27 (8, 11, 12, 19).

However, in the area of gene regulation, significant differences between HSV and VZV exist. For example, VZV lacks a functional α-trans-inducing factor (VP16 or Vmw65) gene which, in HSV-infected cells, is involved in transactivation of IE gene expression (2, 4, 26, 31, 33). Thus, induction of IE genes of VZV during productive infection appears to be mediated by a different mechanism, and the factor(s) responsible for immediate-early gene induction in VZV remains undefined.

There is strong evidence to indicate the presence of VZV in circulating T lymphocytes during the viremic phase of human infection (1, 14, 21, 22, 30, 39), and as a first step toward understanding the transcriptional regulation of VZV genes in these cells, we have investigated the regulatory roles of ORF61, ORF62, and ORF4 in modulating the activity of VZV genes of different kinetic classes using an in vitro transient cotransfection system in human T lymphocytes. In this communication, we show that the gene product of ORF62 is a major regulatory protein of VZV and is capable of upregulating the expression of VZV genes of all three putative kinetic classes. In addition, we present evidence to implicate accessory regulatory roles for the gene products of ORF4 and ORF61 of VZV.

MATERIALS AND METHODS

Cell lines. A CD4-positive, continuous human T cell line, A3.01 (13), was obtained from the AIDS Research and Reference Reagent Program, National Institute of Allergy and Infectious Diseases, and was maintained in RPMI 1640 medium supplemented with 10% fetal calf serum. The cells were routinely screened for mycoplasma contamination. Vero cells were obtained from the American Type Culture...
Collection (Rockville, Md.) and grown in Opti-MEM medium (GIBCO-BRL) with 5% fetal calf serum.

**Plasmid constructs.** Recombinant plasmids were constructed by standard cloning procedures (25). The plasmids pGORF4, pGORF61, and pGi26 contain a single copy of ORF4, ORF61, and ORF62 of VZV, respectively, and are driven from their cognate promoters. Detailed descriptions of the construction of these plasmids have been published elsewhere (11, 18, 27).

To create p4CAT, pGORF4 was restricted with NcoI and then treated with mung bean nuclease followed by digestion with BamHI. Following gel electrophoresis, a 3.6-kb fragment containing the promoter region of ORF4 was isolated. The coding region of the chloramphenicol acetyltransferase (CAT) gene was isolated from pCAT Basic (Promega) as follows: the pCAT Basic plasmid was linearized by being digested with PstI and then treated with mung bean nuclease. Next, pCAT Basic plasmid that had been linearized with PstI was cut with BamHI and subjected to agarose gel electrophoresis. A 1.7-kb fragment containing the coding region of the CAT gene was isolated, and this fragment was then ligated to the 3.6-kb fragment containing the ORF4 promoter. In the resultant construct, p4CAT, the CAT gene is placed under the transcriptional control of the ORF4 promoter embedded in a segment extending from −2 to −888 relative to the initiator AUG codon of ORF4.

To create p61CAT, pGi26 was restricted with NruI and EcoRI followed by mung bean nuclease treatment to blunt the cut ends (in pGi26, the BglII-HpaI fragment from the Ellen strain of VZV contains an additional NruI site 605 bp downstream of the NruI site in the published DNA sequence of the Dumas strain [31a]). After agarose gel electrophoresis, a 4.4-kb fragment was isolated and recircularized by blunt-end ligation with T4 DNA ligase. This construct was designated pGi26ΔEN. The pGi26ΔEN lacks a functional ORF62, and only 760 bp upstream of the terminator TGA codon of ORF62 is retained in this construct. The plasmid pGi26ΔEN was then digested with NcoI, and the ends were blunted with mung bean nuclease and then cut with BamHI. After agarose gel electrophoresis, a 4.1-kb fragment was isolated. This fragment was ligated to a 1.7-kb BamHI-PstI fragment (the PstI end blunted with mung bean nuclease) containing the coding region of the CAT gene as described earlier. The resultant construct was designated p61CAT. In p61CAT, the CAT gene is under the transcriptional control of the ORF61 promoter embedded within a segment extending from +65 to −1400 relative to the mRNA cap site of ORF61 (27).

The plasmid pgpIVCAT was constructed as follows. The segment extending from +63 to −363 (with reference to the transcription start site) of the gpIVORF (ORF67) was excised from the BamHI K fragment (10, 28) after being digested with BamHI and AccI. The ends of this fragment were blunted by filling in with Klenow enzyme before BglII linkers were added. This was then ligated into the BglII site of pCAT3M (kindly provided by G. Khoury, National Institutes of Health, Bethesda, Md.). In the resultant construct, pgpIVCAT, the CAT gene is under the transcriptional control of the gpIVORF promoter. In constructing pgpVCAT, the segment extending from +37 to −541 (with reference to the transcription start site) of gpVORF (ORF14) was excised from the EcoRI P fragment (28, 38) after being digested with BstNI and EcoRI. The resultant fragment was blunted by filling in with Klenow enzyme. After BglII linkers were added, this fragment was ligated into the BglII site of pCAT3M. The fusion joints of all of the VZV promoter-CAT constructs were verified by DNA sequencing. The pTKCAT that contains the VZV thymidine kinase promoter-CAT fusion has been described previously (18).

The plasmid pCMV4 was created by cutting pGORF4 with NcoI and BamHI (the NcoI end was filled in with T4 DNA polymerase) to generate a 2.1-kb fragment with the coding region of ORF4. This fragment was ligated to pG310 containing the IE gene I (IE-I) promoter of human cytomegalovirus (HCMV) (kindly provided by E. Mozeska, Stanford University, Palo Alto, Calif.) that had been digested with EcoRI and BamHI (the EcoRI end was filled in with T4 DNA polymerase). In the resultant construct, pCMV4, the coding region of ORF4 was placed under the control of the strong IE promoter of HCMV.

To create pCMV62, the EcoRI E fragment (28, 38) was digested with ScaI and BglII. A 5.0-kb fragment containing the entire coding region of ORF62 was isolated by gel electrophoresis. This fragment was ligated with pG310 that had been digested with EcoRI (subsequently blunted with mung bean nuclease) and BamHI. In the resultant construct, pCMV62, the coding region of ORF62 was placed under the control of the strong IE promoter of HCMV. In all of the chimeric constructs generated, the orientation and the integrity of the fusion joints were verified by DNA sequencing.

The pCMV61 construct containing the coding region of ORF61 placed under the control of the IE promoter of HCMV was generously provided by P. R. Kinchington, The Eye and Ear Institute, University of Pittsburgh, Pittsburgh, Pa.

**DNA transfections.** In transient transfection assays, routinely 5 μg of target construct DNA and 5 μg of effector construct DNA were used, unless indicated otherwise. In each transfection experiment, the total DNA amount was kept constant at 20 μg by adding pBS plasmid (Stratagene) DNA as a carrier. For electroporations, A3.01 cells were washed twice with serum-free RPMI and resuspended in the same medium without serum, glutamine, or antibiotics at a density of 3 × 10⁷ cells per ml. Aliquots (0.5 ml each) of the cell suspension were mixed with plasmid DNA in an electroporation chamber and incubated on ice for 10 min. The cells were then electroporated with two pulses by using a Progenitor II electroporator (Hoefer Scientific Instruments) with the settings at 200 V, 760 μF, and 10 ms. The cells were then incubated on ice for a further 15 min after pulsing. After 1 ml of growth medium had been added, the cells were then transferred into 24-well tissue culture plates and were grown for 48 h before being harvested. Vero cells were transfected with DNA by using lipofectin (BRL Life Technologies, Inc.) in accordance with the manufacturer’s instructions.

**DNA sequencing.** CsCl density gradient-purified plasmid DNA was sequenced with the Sequenase DNA sequencing kit (U.S. Biochemical Corp.) according to published procedures (32).

**CAT assays.** Cells were harvested 48 h after DNA transfections, and CAT assays were done essentially as described by Gorman et al. (15). The cells were washed once with phosphate-buffered saline and resuspended in 0.25 M Tris HCl (pH 7.8) and disrupted by three cycles of freeze-thawing. Protein concentrations in cell lysates were determined by using the Bio-Rad protein determination kit, according to the manufacturer’s instructions. The CAT activity was assayed by using the same amount of total protein for all samples in an individual experiment. In certain experiments, samples displaying extremely high levels of CAT activity were repeated after appropriate dilutions of the samples had been made, such that the linear range of the assay was maintained. The CAT activity was quantitated with a Phos-
phorImager scanner with Image Quant software from Molecular Dynamics (Sunnyvale, Calif.). All experiments were repeated at least three times with independent DNA transfections.

RESULTS

Basal promoter activity of VZV genes of different kinetic classes. The five promoters evaluated in the present study were selected to represent the three putative kinetic classes of VZV genes. ORF4 and ORF61 are putative IE (α) genes, while the thymidine kinase gene (tk) is a putative early (β) gene. The two structural genes, glycoprotein IV (gpIV) and glycoprotein V (gpV), are putative late (γ) VZV genes. The levels of basal promoter activities of all of the VZV genes representing different kinetic classes used in the present study were very low in A3.01 cells. As shown in Fig. 1, the acetylation of [14C]chloramphenicol was less than 1% for all of the VZV promoter-CAT chimerae tested, whereas a control construct with the human immunodeficiency virus long terminal repeat promoter fused to CAT demonstrated 15% acetylation (data not shown). This indicates that the low level of basal activity elicited by the VZV promoters was due not to poor transfectability of the A3.01 cells but rather to poor VZV promoter activity.

Modulation of VZV gene promoters by the gene product of ORF62 of VZV. In cotransfection experiments, the pGii6 plasmid (ORF62 driven from the cognate promoter) transactivated representative gene promoters of putative IE (α) and early (β) kinetic classes. As shown in Table 1, a 9.2-fold induction was seen with p4CAT, whereas a 32-fold induction above the basal level was elicited with p61CAT. The pTKCAT, representing a putative early (β) gene of VZV, demonstrated a 38.8-fold induction above the basal level of expression with pGii6. pppVCAT and pppVCAT, representing promoters of the late (γ) kinetic class genes, were not transactivated above basal-level expression. When pCMV62 (ORF62 driven from the IE promoter of HCMV) was used in the cotransfection experiments, a similar trend of transactivation was seen (Table 2). However, it should be noted that the expression of ORF62 by the strong HCMV IE promoter resulted in an 18.3-fold increase in expression of p4CAT above that seen with pGii6 (compare Tables 1 and 2), whereas the pTKCAT expression was increased by only 3-fold with pCMV62 above that seen with pGii6. Interestingly, the p61CAT did not show any increase with pCMV62 above that seen with pGii6, indicating a possible saturation phenomenon (compare Tables 1 and 2). It is likely that the enhanced activation of the target constructs with pCMV62 occurs as a result of enhanced expression of IE62 from the strong constitutive HCMV IE promoter. If this were the case, then increasing the effector DNA in cotransfections with the targets should lead to increased activation of the responsive targets. To test this possibility, we used pTKCAT as a representative responsive target to perform a series of cotransfections varying the amounts of effector DNA (pGii6) with a fixed amount of target DNA. As shown in Fig. 2, there was a dose-dependent activation of the pTKCAT target. In addition, pppVCAT, representing a late

![Graph of basal promoter activity of VZV genes of different kinetic classes.](http://jvi.asm.org/pdf/5300/Fig1.jpg)

**FIG. 1.** Basal promoter activity of VZV genes of different kinetic classes. A3.01 cells were electroporated with 5 μg of the indicated plasmid DNAs as described in Materials and Methods. The cells were harvested 48 h after electroporation, and the level of CAT activity in the cell lysates was assayed by using the same amount of total protein for all of the samples. The CAT activity was quantitated with a PhosphorImager scanner with Image Quant software from Molecular Dynamics.

### Table 1. Modulation of VZV gene promoters by the cognate promoter-driven ORF4, ORF61, and ORF62 in human T lymphocyte cell line A3.01

<table>
<thead>
<tr>
<th>Target construct</th>
<th>Putative kinetic class of the target</th>
<th>Effector construct(s) used in cotransfection</th>
<th>Fold induction</th>
</tr>
</thead>
<tbody>
<tr>
<td>p4CAT</td>
<td>IE</td>
<td>pGii6</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pGii6+pGORD4</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pGii6+pGORD4+pGORD4</td>
<td>59.4</td>
</tr>
<tr>
<td>p61CAT</td>
<td>IE</td>
<td>pGii6</td>
<td>32.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pGii6+pGORD4+pGORD4</td>
<td>102.8</td>
</tr>
<tr>
<td>pTKCAT</td>
<td>Early</td>
<td>pGii6</td>
<td>38.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pGii6+pGORD4+pGORD4</td>
<td>137.0</td>
</tr>
<tr>
<td>pppVCAT</td>
<td>Late</td>
<td>pGii6</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pGii6+pGORD4+pGORD4</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pGii6+pGORD4+pGORD4+pGORD4</td>
<td>32.0</td>
</tr>
</tbody>
</table>

* A3.01 cells were electroporated as described in Materials and Methods. The target and effector constructs were used in 5-μg amounts in cotransfection experiments. In each cotransfection experiment, the total DNA amount was kept constant at 20 μg by adding pBS plasmid (Stratagene) DNA as a carrier. b The fold inductions were calculated as described in the legend to Fig. 2 and are the means of triplicate transfections done in parallel. Standard deviations ranged from 6 to 36%. NI, no detectable induction.
TABLE 2. Modulation of VZV gene promoters by the HCMV IE promoter-driven ORF4 and ORF62

<table>
<thead>
<tr>
<th>Target construct</th>
<th>Effector construct(s) used in cotransfection*</th>
<th>Fold induction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>p4CAT</td>
<td>pCMV62</td>
<td>168.8</td>
</tr>
<tr>
<td></td>
<td>pCMV4</td>
<td>NI</td>
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<tr>
<td></td>
<td>pCMV62+pCMV4</td>
<td>752.0</td>
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<tr>
<td>p61CAT</td>
<td>pCMV62</td>
<td>24.0</td>
</tr>
<tr>
<td></td>
<td>pCMV4</td>
<td>NI</td>
</tr>
<tr>
<td></td>
<td>pCMV62+pCMV4</td>
<td>119.0</td>
</tr>
<tr>
<td>pTKCAT</td>
<td>pCMV62</td>
<td>125.0</td>
</tr>
<tr>
<td></td>
<td>pCMV4</td>
<td>23.0</td>
</tr>
<tr>
<td></td>
<td>pCMV62+pCMV4</td>
<td>238.0</td>
</tr>
<tr>
<td>pgpIVCAT</td>
<td>pCMV62</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>pCMV4</td>
<td>NI</td>
</tr>
<tr>
<td></td>
<td>pCMV62+pCMV4</td>
<td>13.3</td>
</tr>
<tr>
<td>pgpVCAT</td>
<td>pCMV62</td>
<td>NI</td>
</tr>
<tr>
<td></td>
<td>pCMV4</td>
<td>NI</td>
</tr>
<tr>
<td></td>
<td>pCMV62+pCMV4</td>
<td>2.6</td>
</tr>
</tbody>
</table>

* A3.01 cells were electroporated as described in Materials and Methods. The target and effector constructs were used in 5-μg amounts in cotransfection experiments. In each cotransfection experiment, the total DNA amount was kept constant at 20 μg by adding pBS plasmid (Stratagene) DNA as a carrier.

* The fold inductions were calculated as described in the legend to Fig. 2 and are the means of triplicate transfections done in parallel. Standard deviations ranged from 3.7 to 29.4%. NI, no detectable induction.

(γ) gene promoter, showed slight (approximately twofold) activation with pCMV62, although no demonstrable activation was seen with pGi26 (compare Tables 1 and 2). However, no activation of the pgpV promoter was seen within the limits of sensitivity of the assay. To examine the possibility that the lack of demonstrable activation of the late (γ) gene promoters by IE62 may be due to limitations in the sensitivity of the assay, cotransfections with greater amounts of target DNA (25 instead of 5 μg) and various amounts of pCMV62 were done. Under these conditions, IE62 was able to induce demonstrable activation of pgpIVCAT (Fig. 3). However, the pgpV promoter still remained refractory to IE62 (data not shown). Thus, these findings demonstrate the ability of the ORF62 gene product to activate specific VZV genes of all three putative kinetic classes.

Modulation of VZV gene promoters by the gene product of ORF4 of VZV. The ability of the ORF4 gene product to activate VZV genes of different putative kinetic classes was assessed with constructs that expressed ORF4 either from its cognate promoter (pGORF4) or from the strong IE promoter of HCMV (pCMV4) in cotransfection experiments. As shown in Tables 1 and 2, the only VZV gene promoter-CAT chimeras to be activated by the gene product of ORF4 was pTKCAT. The cognate promoter-driven ORF4 elicited a level of induction 2.6-fold above the basal level of expression. However, when the effector (pGORF4) DNA amount was increased in the cotransfections with pTKCAT, a dose-dependent increase in the activation of the pTKCAT was seen (Fig. 2). In addition, when the pCMV4 construct was used as the effector, a 23-fold induction of pTKCAT was seen (Table 2). Thus, it appears that the thymidine kinase promoter responds to the gene product of ORF4 in a concentration-dependent manner. In addition, these results suggest that the direct activation of VZV genes by the gene product of ORF4 may be limited to the putative early (B) genes of VZV.

Synergistic activation of VZV genes by the gene products of ORF4 and ORF62. When pGi26 and pGORF4 were used in combination as effectors in the cotransfection experiments, there was synergistic activation of VZV genes of all three putative kinetic classes (Table 1). With p4CAT, the combination of pGORF4 and pGi26 elicited an induction that was 4.7-fold higher than what was seen with pGi26 alone. With p61CAT, the combination of pGORF4 and pGi26 elicited an induction that was threefold higher than that with pGi26 alone. With pTKCAT, the combination of pGORF4 and
pGi26 yielded an induction 2.5-fold above what was seen with pGi26 alone. Furthermore, the combination of pGi26 and pGORF4 was able to induce the expression of pppIVCAT. This activation was further augmented when pCMV62 and pCMV4 were used in combination as effectors in the cotransfection experiments instead of pGi26 and pGORF4 (compare Tables 1 and 2). However, the fold induction elicited by the combination over the pCMV62-induced activation closely paralleled the trend that was seen with the cognate promoter-driven ORF4 and ORF62. The enhancement of activation of p4CAT, p61CAT, and pTKCAT by the combination of pCMV62 and pCMV4 was 4.5-, 4.9-, and 1.9-fold, respectively. Nonetheless, a sevenfold enhancement of activation was seen with pppIVCAT when both pCMV4 and pCMV62 were used in combination instead of pCMV62 alone in cotransfections performed with 5 µg of target DNA (Table 2). Furthermore, pppVCAT showed a 2.6-fold induction above the basal-level activity when both pCMV62 and pCMV4 were used in combination, whereas pCMV62 alone was unable to elicit any induction of pppVCAT.

**The effects of the ORF61 gene product on the expression of VZV genes.** In cotransfection experiments, ORF61, whether expressed from the cognate promoter or from the strong IE promoter of HCMV, failed to transactivate directly the expression of any of the VZV gene promoter-CAT chimeric tested (data not shown). Nonetheless, in combination with pGi26, the pGORF61 (cognate promoter-driven ORF61) was able to synergize the activation of p4CAT, p61CAT, and pTKCAT (Table 1). Having established the ability of ORF61 to synergize the ORF62-mediated activation of VZV genes, we next examined whether the synergistic effect of ORF61 was dose dependent. As shown in Fig. 4, the synergistic effect of ORF61 on ORF62-mediated activation of pTKCAT did not appear to be linear with increasing amounts of pGORF61. In addition, pGORF61 was able to synergize the activation of pTKCAT by pGORF4, although the level of enhancement of activation was rather low (Table 1). Furthermore, when all three putative IE genes were used in combination as effectors in cotransfection experiments, the degree of activation of p4CAT, p61CAT, and pTKCAT was more than that with pGi26 and pGORF4 together (Table 1). These findings indicate that the gene product of ORF61 is able to augment the transactivation ability of the gene products of ORF4 and ORF62 when coexpressed in human T lymphocytes. However, this is in contrast to the situation seen in Vero cells, in which ORF61 has been shown to repress both the ORF62- and the ORF4-mediated activation of pTKCAT (27). As shown in Fig. 5, the ability of ORF61 in Vero cells to repress both the ORF62- and the ORF4-mediated activation of pTKCAT was reconfirmed in this study. The regulatory role of ORF61 thus appears to be cell type dependent.

**DISCUSSION**

As part of a continuing study to understand the regulation of temporal gene expression in VZV, we have analyzed the ability of the gene products of ORF4, ORF61, and ORF62 to modulate the expression of VZV genes of different putative kinetic classes in the A3.01 cell line, which is a permanent cell line of human T lymphocytes. During natural VZV infection, especially in the prodromal and early clinical phases, when virus actively replicates in the human host, VZV can be isolated from the peripheral blood mononuclear cells (1, 14, 21, 22, 30, 39). Of these peripheral blood mononuclear cells, predominantly T lymphocytes appear to be able to support VZV growth, thus implying an important role for T cells in VZV biology in vivo.

First, it is of interest to note that all of the VZV gene promoters used in the present study displayed very low-level basal activity in a lymphocytic-cell background (Fig. 1). This is consistent with reports from other investigators using a variety of different cell backgrounds for a number of VZV genes (3, 9, 11, 18, 26, 27).

The gene product of ORF62 was able to activate both ORF4 and ORF61 promoters. This is of special significance,
since only these two VZV genes have been shown to have any modulatory activity on VZV gene expression in addition to that of ORF62. Furthermore, in contrast to ICP4 of HSV, which represses the expression of other IE genes (36), the VZV homolog, IE62, activates these putative IE genes of VZV. The ability of the ORF62 gene product to activate the thymidine kinase gene promoter (tk) and glycoprotein I (gpl) promoter in Vero cells has been previously reported (18). In the present study, we too were able to demonstrate the activation of the tk promoter by the ORF62 gene product in T lymphocytes, indicating that the ORF62 gene product is capable of activating putative early (β) gene promoters in a cell type-independent fashion. Of the two late (γ) gene promoters tested, the gpIV promoter was clearly induced by IE62. However, the fact that larger amounts of target (25 versus 5 μg of pp71CAT) were required to demonstrate substantial activation of pp71CAT (compare Tables 1 and 2 with Fig. 3) suggests inherently weak promoter activity of the gpIV gene in T lymphocytes.

Recently, Kinchington et al. (20) demonstrated the abundant presence of the ORF62 gene product in the virion tegument of VZV. Since the gene product of VZV ORF10 lacks any transactivator function (6, 26), unlike its HSV homolog, α-trans-inducing factor (VP16 or Vmw65), which is a potent transactivator of IE (α) genes of HSV (2, 4, 31, 33), the incorporation of relatively large amounts of ORF62 gene product in the virion may be a compensatory mechanism to ensure rapid expression of IE (α) genes of VZV upon entry into a susceptible cell. This possibility is well illustrated by the findings of the present study, which clearly demonstrates the ability of the gene product of ORF62 to upregulate the expression of the other two putative IE (α) genes of VZV.

The gene product of ORF4 has been shown to transactivate the VZV tk gene promoter as well as the glycoprotein I (gpl) promoter of VZV in Vero cells (18). Although in these studies the level of gp1 promoter activation was modest (twofold), in the present study the only gene promoter that was responsive to the gene product of ORF4 was the thymidine kinase (tk) promoter. Furthermore, we were not able to detect any autoregulatory activity of the ORF4 promoter when ORF4 was coexpressed either from the cognate promoter or from the IE promoter of HCMV with pg4CAT. It would be interesting to evaluate other putative early (β) genes of VZV such as ORF28 (the DNA polymerase gene) and ORF69 (the major DNA-binding protein) to determine whether the gene product of ORF4 is specifically capable of inducing only the early (β) genes. However, it should be noted that although the ORF4 gene product by itself was not able to activate any VZV gene promoters other than the thymidine kinase promoter, it was capable of synergizing the transactivation of promoters of all kinetic classes induced by the gene product of ORF62 (Tables 1 and 2).

It is of interest to note that more potent activation of targets was seen when the gene products of ORF62 and ORF4 were expressed from the strong constitutive IE promoter of HCMV. Two likely explanations for this enhanced effect are (i) enhanced expression of the activator from the strong HCMV IE promoter and (ii) elimination of possible interference or feedback from the gene product onto the cognate promoter, thereby resulting in enhanced expression of the activator. However, the ability of pg926 and pg04RF4 to activate the targets in a concentration-dependent manner (Fig. 2) may argue against the latter possibility.

Unlike its HSV homolog ICP0, the gene product of ORF61 was not able to activate or suppress the expression of any of the VZV genes tested in the present study when expressed either from its cognate promoter or from the HCMV IE promoter (data not shown). Nonetheless, the fact that in the presence of the ORF61 gene product, both the ORF4 and the ORF62 gene products displayed enhanced activity (Tables 1 and 2; Fig. 4) supports the conclusion that the gene product of ORF61 plays a regulatory role in VZV gene expression. Cabirac et al. (3) observed a similar synergizing effect of the ORF61 gene product on the ORF62-mediated transactivation of the VZV tk promoter in CV-1 cells. However, Nagpal and Ostrove (27) recently demonstrated that the gene product of ORF61 actually was capable of repressing the transactivation induced by both ORF4 and ORF62 in Vero cells. In confirming the results of Nagpal and Ostrove we too observed a reduction in ORF4- or ORF62-mediated induction of the VZV tk promoter in the presence of the ORF61 gene product in Vero cells (Fig. 5). Thus, it appears that the gene product of ORF61 is able to act as an accessory transactivator or as a trans-repressor in a cell type-dependent manner in regulating the VZV gene expression. Although it is tempting to suggest that this unique cell type-dependent regulatory role of the ORF61 gene product may play a role in VZV latency and host range, further studies are needed to evaluate the regulatory role of the ORF61 gene product in neuronal cells as well as in other permissive cells, such as human foreskin fibroblasts, in modulating ORF62- and ORF4-induced VZV gene expression.

The fact that the glycoprotein V (gpV) promoter remained consistently refractory to activation by the ORF62 gene product was surprising. In vitro studies have clearly demonstrated an abundance of gpV protein as well as of its transcript in VZV-infected cells (23), indicating substantial transcriptional activity of this late (γ) promoter during infection. Even when ORF4 and ORF61 were used in combination with ORF62, activation of gpV was minimal. Since the basal activity of the gpV promoter appears to be weak (Fig. 1), it is possible that the enhanced activity of the gpV promoter during VZV infection may be mediated by a virus-encoded transactivator protein(s) other than the gene product of ORF62, ORF4, or ORF61. Alternatively, it is possible that the construct pgpV CAT lacks critical cis elements essential for activation by the gene product of ORF62. We are in the process of investigating these possibilities.

In conclusion, we have demonstrated that the gene product of ORF62 is a major regulatory protein in VZV and is capable of activating VZV genes of all three putative kinetic classes. The gene products of ORF4 and ORF61 play an accessory regulatory role in synergizing the activation of VZV genes induced by the gene product of ORF62.

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REFERENCES

32. Perera, L. P. Person’s observation.