Role of Nectin-1, HVEM, and PILR-α in HSV-2 Entry into Human Retinal Pigment Epithelial Cells

Sripaad Y. Shukla,1,2 Yogesh K. Singh,1,2 and Deepak Shukla1,3

PURPOSE. Herpes simplex virus-type 2 (HSV-2) can cause acute retinal necrosis (ARN), which can lead to exudative and rhegmatogenous retinal detachment, yet little is known about the cellular and molecular mechanisms of HSV-2 entry into retinal pigment epithelial (RPE) cells. The goal of this study was to establish the identity of the critical receptors used by the virus for infection.

METHODS. A reporter HSV-2 virus, which expresses β-galactosidase, was used to quantify entry into RPE cells, and viral replication was ascertained using a plaque assay. Flow cytometry and immunocytochemistry were used to determine cellular expression of entry receptors. Localization of these receptors to the apical or basal surface of RPE cells was determined with immunocytochemistry. The necessity of these receptors, individually and in combination, for viral entry was established using receptor-specific antibodies and siRNAs.

RESULTS. RPE cells are highly susceptible to HSV-2 entry and replication. Several assays demonstrated the expression of the entry receptors nectin-1, HVEM, and PILR-α and their localization primarily to the apical surfaces of RPE cells. Receptor-specific antibodies and siRNA knockdown of receptors significantly reduced viral entry and implicated nectin-1 as an important receptor, with HVEM and PILR-α potentially also contributing to entry.

CONCLUSIONS. HSV-2 is capable of developing a productive infection in RPE cells by using nectin-1 as an important entry receptor. To lesser degrees, HVEM and PILR-α may also contribute to HSV-2 entry into RPE cells. (Invest Ophthalmol Vis Sci. 2009;50:2878–2887) DOI:10.1167/iovs.08-2981

Herpes simplex virus (HSV) is the leading cause of infectious blindness in developed nations.1 It is also known to infect a variety of cell types and to cause numerous ocular diseases, including blepharitis, stromal keratitis, chorioretinitis, and retinitis, among others.2,3 Each year there are 500,000 primary cases of HSV-2 infection in the United States, and at least 22% of the population has a latent infection.4,5 It has been accepted that virtually all patients infected with HSV-2 will have recurrent disease.3 The urgency of developing a better understanding of HSV-2 pathogenesis is increasing given the discovery of new drug-resistant strains.6 The prevalence of perinatal infections ranges from 1 in 2000 to 1 in 5000 births per year in the United States.7 HSV-2 infection of the retina is also the leading cause of acute retinal necrosis in persons younger than 25.8,9 HSV-2 induced retinitis and acute retinal necrosis (ARN) are devastating infections seen in both immunocompromised and immunocompetent patients.10–14 ARN is a blinding disease marked by rapid progressive peripheral retinal necrosis and was first described in humans by Urayama.15 It has been found that ARN caused by HSV may be the result of direct viral invasion or a recurrence of a previous episode of retinitis or keratitis caused by the virus.5,10–13 Latent infections have been known to be triggered by such events as trauma, neurosurgery, or high-dose corticosteroids.16 The disease is typically characterized by inflammatory orbitopathy, proptosis, and optic nerve involvement and can lead to exudative and rhegmatogenous retinal detachment.19–21 Because of the escalating prevalence of HSV-2, it has been predicted that the incidence of retinitis and ARN will grow even higher.22

In general, HSV entry into host cells is a multistep process that begins with the specific binding of viral envelope glycoproteins to the host-cell surface receptors. Glycoprotein (g) B and gC mediate the initial attachment of the virions to certain cell-surface glycosaminoglycans, most notably heparan sulfate.23,24 After the interaction with heparan sulfate, a conformational change allows gD to bind to its receptor,25–27 Then a concerted action involving gD, its receptor, three additional HSV glycoproteins (gB, gH, gL), a gB coreceptor, and possibly other gH coreceptors triggers fusion of the viral envelope with the host cell membrane.28–31 Recently, paired immunoglobulin-like type 2 receptor-alpha (PILR-α), has been implicated as a gB-coreceptor for HSV-1 entry.32 The significance of PILR-α, however, is not known for HSV-2 entry into its host cells.

HSV-1 and HSV-2 may differ in the cellular receptor to which gD binds. Several known gD receptors are categorized into three structurally unrelated families. These include nectin-1 and nectin-2, members of the immunoglobulin superfamily;2,5–7,23,32,36 HVEM, a member of the tumor necrosis factor (TNF) receptor family;33,34 and a modified form of heparan sulfate, 3-O-sulfated heparan sulfate (3-O-S HS).24,52,53 Nectin-1 and nectin-2 mediate the entry of HSV-1 and HSV-2, though the HSV-1 entry mediating activity of nectin-2 is limited to some mutant strains.25,33,34 Nectin-1 is extensively expressed in human cells of epithelial and neuronal origin, whereas nectin-2 is widely expressed in many human tissues but has limited expression in neuronal cells.35,37 HVEM mediates the entry of HSV-1 into T-lymphocytes and trabecular meshwork cells and of HSV-2 entry into corneal fibroblasts.35,38,39 HSV-1, but not HSV-2, entry is known to be mediated by 3-O-S HS, which is expressed in many human cell lines.24,36

Retinal pigment epithelial cells have a vital role in the maintenance of the human retina, and HSV-2 infection in these cells has disastrous consequences for vision. Despite this, the identity of important HSV-2 entry receptors in RPE cells re-

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Cell-culture inserts (Millicell; Millipore, Billerica, MA) with a 1-
m pore size were plated
on the apical and basal surfaces of RPE cells. Cell-culture inserts
were used as controls.

Antibody Blocking of Receptors

RPE cells were plated onto 96-well plates, and the appropriate antibody
was added in serial dilution. Anti–PRR1 (specific for nectin-1), anti–HVEM,
and anti–PILR-α antibodies were used to block the corresponding recep-
tors. The plate was incubated with primary antibody at room temperature
for 2 hours. Viral entry assays were then performed using identical doses
of HSV-2(333)gJ- virus. FITC-conjugated anti–mouse IgG and FITC-conjugated
anti–rat IgG antibodies were used as background controls. Cells were then examined by fluorescence-activated cell sorter (FACS) analysis.

Immunocytochemistry

Chamber slides (Laboratory-Tek; Nunc, Rochester, NY) were plated
with monolayers of RPE cells to visualize the receptors on the cell-
surface. Cells were incubated at 4°C for 45 minutes with anti–nectin-1
(1:25 dilution), anti–HVEM (1:10 dilution), or anti–PILR-α (1:25 dilution)
primary antibody. They were then washed six times with cold
PBS and fixed with acetone for 10 minutes at ~20°C. Cells were then
blocked with PBS containing 10% calf serum for 15 minutes and
incubated at 37°C for 30 minutes with the appropriate secondary
antibodies (1:250 dilution), as described for flow cytometry. After
incubation with secondary antibody, cells were washed six times with
PBS and imaged using laser-scanning spectrum confocal microscopy
(TCS SP2; Leica, Wetzlar, Germany). Cells treated only with the sec-
ondary antibody were used as controls.

Immunocytochemistry was also used to image receptor expression
on the apical and basal surfaces of RPE cells. Cell-culture inserts
(Millicell; Millipore, Billerica, MA) with a 1-μm pore size were plated
with monolayers of RPE cells and exposed to primary antibodies on the
apical or basal surface. Specific antibodies, their dilutions, and the
remainder of the procedure were the same as those used in the
previous immunocytochemistry assay. The side not exposed to the
antibodies was incubated with an equivalent volume of PBS containing
5% BSA. Cells exposed only to the appropriate secondary antibody
on the apical or basal surface were used as controls.

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tor. The plate was incubated with primary antibody at room temperature
for 2 hours. Viral entry assays were then performed using identical doses
of HSV-2(333)gJ- virus, as described previously. Cells incubated with secondary antibody, cells were washed six times with
PBS and imaged using laser-scanning spectrum confocal microscopy
(TCS SP2; Leica, Wetzlar, Germany). Cells treated only with the sec-
ondary antibody were used as controls.

siRNA Interference of Major Receptors

siRNAs that downregulated nectin-1 (NM_002855_1; Sigma), HVEM
(NM_003820_1, Sigma), and PILR-α (catalog no. sc-89726; Santa Cruz
Biotechnology, Inc.) were used to interfere with the expression of these
receptors. RPE cells were plated onto six-well culture dishes and
were transfected with the corresponding RNA duplexes or control-scrambled
RNA duplexes. After 48 hours, cells were lysed with Cell Dissociation
Buffer (Invitrogen Corp.) and were replated onto 96-well plates. An ali-
hours after infection, the cells were fixed with fixative buffer (2% formaldehyde and 0.2% glutaraldehyde) at room temperature for 20
minutes, followed by Giemsa staining for 25 minutes. The cells were
then washed five times with nanopure water, and the numbers of
plaques were counted as a measure of viral replication. Images were
taken using the 10× objective of a Zeiss microscope (Axiovert 100;
Carl Zeiss).

Flow Cytometry

Flow cytometry analysis was performed to determine cell surface
expression of nectin-1, HVEM, and PILR-α. Monolayers of approxi-
mately 2 × 10⁶ RPE cells were transferred to 1.5 mL Eppendorf tubes,
and the appropriate secondary antibody (1:1000 dilution) was added, and the dishes were incubated at 37°C for 20
minutes, followed by Giemsa staining for 25 minutes. The cells were
then washed five times with nanopure water, and the numbers of
plaques were counted as a measure of viral replication. Images were
taken using the 10× objective of a Zeiss microscope (Axiovert 100;
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mains unknown. In this study we sought to characterize the cellular
and molecular mechanisms of HSV-2 entry into RPE
cells. In this study, we demonstrate that nectin-1, HVEM, and
PILR-α are primarily expressed on the apical surfaces of RPE
cells. We also demonstrate that HSV-2 uses nectin-1 to enter
RPE cells yet is also capable of using HVEM and possibly PILR-α
for entry. This is the first study to investigate a role for PILR-α
in HSV-2 infection and the first report of a natural target cell
type in which nectin-1 was found to significantly contribute to
HSV-2 entry.

Materials and Methods

Cells, Viruses, and Antibodies

RPE cells were provided by Beatrice Y. J. T. Yue (University of Illinois,
Chicago). They were originally obtained from ATCC (Manassas, VA)
and are spontaneously arising ARPE-19 cells. The cells were grown in
1-glutamine containing Dulbecco’s modified Eagle’s medium (DMEM)
from Invitrogen (Carlsbad, CA) supplemented with 10% fetal bovine
serum (FBS). Cells were trypsinized and passaged after reaching con-
fluence.

Patricia Spear (Northwestern University, Chicago, IL) provided
African green monkey kidney (Vero) cells, and murine melanoma
(B78H1) cells. These cells were cultured as previously described. HSV-2(333) and HSV-2(333)gJ- viruses were also provided by Patricia
Spear. The virus stocks were propagated in complementing cell
lines, titred on Vero cells, and stored at ~80°C.

Antibodies were used for poliovirus receptor-related 1
(PRR1) antibody, specific for nectin-1 (Beckman Coulter, Fullerton,
CA) and monoclonal mouse anti–nectin-1 (Zymed Laboratories, San
Francisco, CA; catalog no. 57–5900). Monoclonal mouse anti–HVEM
antibody was obtained from Santa Cruz Biotechnology Inc. (Santa Cruz,
CA; catalog no. sc-74089). Monoclonal rat anti–PILR-α antibody was
purchased from Dendritics (Lyon, France; catalog no. ddx0230). FITC-
conjugated anti–mouse IgG and FITC-conjugated anti–rat IgG antibod-
ies were obtained from Sigma-Aldrich (St. Louis, MO).

Viral Entry Assays

Viral entry assays were based on the quantification of β-galactosidase
expressed from the viral genome. RPE cells and naturally resistant
B78H1 cells were washed with 1× phosphate-buffered saline (PBS)
and were exposed to 50 μl serially diluted recombinant HSV-2(333)gJ-, which expresses β-galactosidase after entry into cells. Virus was seri-
ally diluted in PBS with 3% bovine serum albumin (BSA). After 6 hours,
cells were washed with 1× PBS and incubated with the β-galactosidase
substrate, o-nitrophenyl-β-D-galactopyranoside (ONPG: ImmunoPure;
Pierce, Rockford, IL), as previously described. The enzymatic activity
was monitored at 410 nm by spectrophotometry (spectra MAX 190;
Molecular Devices, Sunnyvale, CA). HSV entry into RPE and B78H1 cells
was confirmed qualitatively by 5-bromo-4-chloro-3-indolyl-β-
D-galactopyranoside (X-gal) assays, as previously described. In essence,
cells were infected for 6 hours with the reporter virus, then
washed, fixed, permeabilized, and incubated with the X-gal substrate,
which produces a blue color in cells when β-galactosidase acts on it.
Microscopy was performed using the 20× objective of the inverted
microscope (Axiovert 100M; Carl Zeiss, Thornwood, NY). Advanced
software (Slidebook version 3.0; Olympus, Center Valley, PA) was used
for images. All experiments were repeated a minimum of three times
unless otherwise noted.

Time Point Plaque Assay

Confluent monolayers of RPE, B78H1, and Vero cells (approximately
10⁶) in 24-well culture dishes were infected with HSV-2(333) at 0.01
plaque-forming units (PFU)/cell or mock infected for 2 hours at 37°C.
After removal of the inoculum, 1 mL cell-type appropriate media was
added, and the dishes were incubated at 37°C. At 0, 24, 48, and 72
of the cells was set aside to be used for Western blot analysis. Cells were also transfected with nectin-1 and HVEM siRNA or all three siRNAs to determine any cumulative effect. Viral entry assays were then performed, as previously described, with serial dilutions of HSV-2(333)gJ- /H9252-galactosidase–expressing recombinant HSV-2(333)gJ- virus at the PFU indicated. After 6 hours, the cells were washed, permeabilized, and incubated with ONPG substrate for quantification of β-galactosidase activity. Enzymatic activity was measured at an optical density (OD) of 410 nm with a spectrophotometer. In this and other figures each value shown is the mean of three or more determinations (±SD).

Western Blot Analysis of Receptor Expression

The siRNA-downregulated receptors were tested for expression by Western blot analysis. Whole cell lysates of the siRNA-transfected cells previously set aside were immediately boiled for 10 minutes, and equal amounts of protein were subjected to 10% SDS-PAGE and electroblotted onto a nitrocellulose membrane. Nonspecific binding was blocked using 5% nonfat milk in PBS for 2 hours at 37°C. The membrane was incubated with primary antibodies to HVEM (1:1000; Santa Cruz Biotechnology, Inc.), nectin-1 (1:1000; Zymed Laboratories), and PILR-α (1:500; Dendritics) or β-actin (1:5000; Sigma) overnight at 4°C. The membrane was then washed five times for 5 minutes each time with 0.1% Tween 20/PBS, followed by incubation for 1 hour with HRP-conjugated anti–mouse secondary antibody for nectin-1 and HVEM (catalog no. 115-035-062; 1:20,000; Jackson Immunoresearch, West Grove, PA) and HRP-conjugated-streptavidin for PILR-α (1:10,000; Thermo Scientific, Rockford, IL). The membrane was again washed five times for 5 minutes each time with 0.1% Tween 20/PBS, and bands were visualized by exposure to x-ray film after the addition of chemiluminescent substrate (ECL; Thermo Scientific).

Statistical Analysis

All experiments were conducted a minimum of three times with similar results, and quantitative data are expressed as mean ± SD. A paired t-test was performed for quantitative data to establish statistical differences between experimental and control groups (P < 0.05).
RESULTS

Viral Entry and Replication in RPE

To establish HSV-2 entry in RPE cells, confluent monolayers of cells were plated in 96-well culture dishes and infected with serial dilutions of recombinant HSV-2(333)gJ-, which expresses β-galactosidase on entry into cells. Naturally resistant B78H1 cells were used as a negative control. Viral entry was measured after 6 hours of infection. As shown in Figure 1A, there was significantly more entry in RPE cells than in B78H1 cells in a dose-dependent manner. Similar results were also obtained when the cells were analyzed for HSV-2 entry using the insoluble β-galactosidase substrate X-gal (Fig. 1B). As expected, no β-galactosidase activity was observed in B78H1 cells, but activity was observed in RPE cells (dark).

Accepting the ability of HSV-2 to enter RPE cells, we sought to determine whether HSV-2 entry into RPE cells leads to productive viral replication. As shown in Figure 2A, RPE and Vero cells exposed to wild-type HSV-2(333) at 0.01 multiplicity of infection produced a large number of plaques over time compared with the naturally resistant B78H1 cells. Vero cells were used as a positive control. The number and size of plaques were similar between RPE and Vero cells. Typical plaques formed in each of the cells after 48 hours of infection are shown in Figure 2B. These results demonstrate the ability of HSV-2 to both enter and replicate in RPE cells.

Identification and Expression of Entry Receptors

Next, with the use of flow cytometry and immunofluorescence, we determined which of the known HSV-2 entry receptors are expressed on RPE cells. Flow cytometry demonstrated the expression of nectin-1 and HVEM. Interestingly, PILR-α, a reported coreceptor for HSV-1 entry, was also expressed. Although the expression of nectin-1 was most discernible (Fig. 3A), HVEM and PILR-α (Figs. 3B, 3C) were also clearly detected on the surfaces of RPE cells. To further verify and visualize the cell surface expression of the receptors, laser scanning confocal microscopy was used for immunofluorescence assay. Receptor-specific primary antibodies and FITC-conjugated secondary antibodies were used. The results shown in Figure 4, confirmed the expression of nectin-1, HVEM, and PILR-α on RPE cells. Control cells that were only incubated with FITC-conjugated secondary antibody did not demonstrate any significant cell surface fluorescence (Figs. 4B, D, F).

Localization of Receptor Expression

With the knowledge that nectin-1, HVEM, and PILR-α are all expressed by RPE cells, a determination of whether the receptors are preferentially expressed on the apical or basal cell surface was made. A transwell culture system was used to allow selective access to the apical or the basal surface of the RPE cells. Receptor-specific primary antibodies and the appropriate FITC-conjugated secondary antibodies were used in an immunofluorescence assay to analyze the respective surface. Nectin-1, HVEM, and PILR-α were all highly expressed on the apical, but not the basal, cell surfaces (Figs. 5A–F). Cells only treated with the appropriate FITC-conjugated secondary antibody did not exhibit significant fluorescence (Figs. 5G–J). Controls were made for each receptor, but for clarity only one set of controls for each type of secondary antibody used is shown.

Antibody-Blocking and Downregulation of Receptors

Selective expression of nectin-1, HVEM, and PILR-α at the apical surfaces of RPE cells raised the possibility that any of them or all them could be important for HSV-2 entry into RPE cells. To test this, receptor-specific antibodies were used to block viral access to the receptors. Data were analyzed in terms of percentage blocking, the relative amount that entry was reduced compared with control cells. Approximately 40%, 30%, and 25% blocking of HSV-2 entry were observed for cells treated with anti–nectin-1, anti–HVEM, and anti–PILR-α antibody, respectively (Figs. 6A–C). Blocking multiple receptors resulted in an increased effect with an approximately 50% and 60% reduction in entry when anti–nectin-1 and anti–HVEM antibodies or antibodies to all three receptors were used, respectively (Figs. 6D, E).
These results were confirmed by receptor-specific siRNA downregulation of nectin-1, HVEM, and PILR-α expression (Figs. 7Aa–c). The trend of downregulation of nectin-1 demonstrating the largest reduction in entry followed by HVEM and PILR-α was also verified. Downregulation of nectin-1, HVEM, and PILR-α together also resulted in less entry than downregulation of only nectin-1 and HVEM together, confirming the importance of all three receptors (Figs. 8Aa, Ba). Receptor downregulation from the cell surface was verified in parallel by Western blot (Figs. 7Ba–c, 8Ab–c, 8Bb–d).

**DISCUSSION**

Retinitis occurs in persons in all stages of life. In particular, acute retinal necrosis is known to be caused by a few viruses; among them, HSV-2 is the major cause of disease in persons younger than 25 years of age, especially children.8,42 Children with congenital and neonatal HSV-2 infections often develop chorioretinitis and have greater morbidity from this than from any other viral infection.15 Additionally, because of the neural route the virus takes after anterior chamber infection, all patients with anterior chamber viral infection or keratitis can develop retinitis.17 Because of the virus’ ability to establish a latent infection, anyone with a primary infection is at risk

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**FIGURE 4.** Visualization of receptors on RPE cell membrane using immunocytochemistry. Cells were mock treated with PBS containing 3% BSA (B, D, F) or treated with primary antibody for nectin-1 (A), HVEM (C), or PILR-α (E). All cells were then treated with FITC-conjugated secondary antibody and imaged using confocal microscopy. **Green:** receptor expression.

**FIGURE 5.** Receptor expression on the apical and basal surfaces of RPE. Cells were plated in transwell hanging cell culture inserts to allow access to apical and basal cell surfaces. Cells were treated on either their apical or their basal surfaces with primary antibody to nectin-1 (A, B), HVEM (C, D), or PILR-α (E, F). Cells mock treated with PBS containing 3% BSA were used as controls (G–J). All cells were then incubated with FITC-conjugated secondary antibody on the appropriate surface and were imaged by confocal microscopy. FITC-conjugated anti–mouse secondary antibody was used for nectin-1, and HVEM and FITC-conjugated anti–rat secondary antibody was used for PILR-α. **Green:** receptor expression. Controls were made for each of the three receptors, but for clarity one set of controls is shown for each type of secondary antibody.
for retinal disease throughout their life.\textsuperscript{11,17,22,44,45} Reports of HSV-2–induced acute retinal necrosis continue to increase.\textsuperscript{9,18,44,46–48}

Acute retinal necrosis and other retinal infections are devastating and often blinding conditions, yet little is known about the cellular and molecular mechanisms of viral entry into retinal cells. We have demonstrated that RPE cells are highly susceptible to HSV-2 infection and that nectin-1, HVEM, and PILR-\(\alpha\) are primarily localized to the apical cell surface. The study also reveals the novel result that the virus uses nectin-1 and is capable of using HVEM and PILR-\(\alpha\) to enter RPE cells. Ours is the first study to demonstrate the use of nectin-1 as an important receptor for HSV-2 entry into a natural target cell type.\textsuperscript{25,31,39} However, the fact that neither the siRNA interference nor the antibodies could block all viral entry suggests the presence of an as yet unknown receptor. The use of multiple receptors by the virus became evident because of the substantial reduction in viral entry in cells incubated with individual or a combination of receptor-specific antibodies and cells transfected with individual or a combination of receptor-specific siRNAs (Figs. 6–8). Based on the relative entry blocking effect of the three receptors, it appears that nectin-1 is clearly important, followed by HVEM and possibly PILR-\(\alpha\). Interestingly, maximal reduction of entry was found when all three receptors were blocked, suggesting the ability of the virus to use multiple receptors, potentially including an unknown receptor, for entry into the same cell type. The reduction in entry observed when all three receptors were

\textbf{FIGURE 6.} Antibodies to the receptors block HSV-2 entry. Monolayers of cells plated in 96-well culture dishes were incubated with serial dilutions of primary antibodies to nectin-1 (A), HVEM (B), PILR-\(\alpha\) (C), nectin-1 and HVEM (D), or all three receptors (E) for 2 hours. Cells were then exposed to identical doses of HSV-2(333)gJ- (50 PFU/cell), and viral entry was measured 6 hours after infection using a spectrophotometer. The percentage difference in entry between cells treated with control antibody (\(\alpha\)-TGF\(\beta\)R II) and those treated with receptor-specific antibody is reported as the percentage of blocking. Data shown are the means of triplicate determinations and are representative of three independent experiments.

The possibility that HSV can use all three receptors to infect one target cell type.\textsuperscript{25,31,39} However, the fact that neither the siRNA interference nor the antibodies could block all viral entry suggests the presence of an as yet unknown receptor. The use of multiple receptors by the virus became evident because of the substantial reduction in viral entry in cells incubated with individual or a combination of receptor-specific antibodies and cells transfected with individual or a combination of receptor-specific siRNAs (Figs. 6–8). Based on the relative entry blocking effect of the three receptors, it appears that nectin-1 is clearly important, followed by HVEM and possibly PILR-\(\alpha\). Interestingly, maximal reduction of entry was found when all three receptors were blocked, suggesting the ability of the virus to use multiple receptors, potentially including an unknown receptor, for entry into the same cell type. The reduction in entry observed when all three receptors were
blocked can be explained by the significant hindrance in the ability of the virus to bind to an entry receptor. When only one receptor was blocked, the virus was able to use the other receptors and still enter RPE cells. Residual entry, even after all three receptors were blocked, hints at the interesting possibility that other receptor(s) exist that can allow HSV-2 entry. It must also be considered that the receptor-specific antibodies and siRNAs might not have blocked all the receptors present or might have provided incomplete blocking. Given the current understanding of the role of PILR-α in HSV infection, PILR-α cannot be considered to act as a substitute receptor for nectin-1 or HVEM. Rather it may potentially contribute as a coreceptor for HSV-2, as has been described for HSV-1. The role PILR-α in HSV-2 entry, however, may be of less significance than in HSV-1 entry. Viral use of multiple cell surface receptors can be recognized as a means to maximize entry.

The observation that nectin-1 is highly expressed on the apical surfaces of RPE cells is consistent with previous findings. We have confirmed and extended these findings and have discovered that HVEM and PILR-α are also highly expressed on the apical surfaces of RPE cells. This has important implications in providing a molecular rationale for the accepted description of how anterior chamber infection with HSV leads to contralateral retinal necrosis and sparing of the ipsilateral retina. This is known as the Von-Szily reaction. Briefly, it is believed that the virus travels from the ipsilateral ciliary ganglion, through the ipsilateral Edinger-Westphal and suprachiasmatic nuclei, and then crosses over and spreads down the contralateral optic nerve to the ganglion cells of the contralateral retina to the inner nuclear layer and then to the RPE. The ipsilateral retina is spared because of effective immune protection.
within the retina would allow the virus to enter RPE cells from the apical surface using not only nectin-1 but also HVEM and PILR-α. 

Glycosaminoglycans in the interphotoreceptor matrix may also assist the virus in attaching to the apical surfaces of RPE cells and in causing infection. Interestingly, it has been reported that HSV-2–induced retinitis in mice impacts both the ipsilateral and the contralateral retina, which may suggest variations in the exact neural travel mechanisms used by HSV-1 and HSV-2.

The apical surface of the RPE cell is specialized to phagocytose photoreceptor outer segments as a part of the RPE cell’s normal maintenance of the retina itself. Portions of PILR-α are also known to have some homology with tyrosine-based sorting signals involved in the internalization of cell-surface molecules. Thus, it is possible that HSV’s use of PILR-α in RPE cells takes advantage of the cells inherent phagocytic nature and assists in viral uptake. It is also known that PILR-α has an immunoreceptor tyrosine-based inhibitory motif in its intracellular portion. Activation of this receptor leads to the down-regulation of immune response through Src homology-2 domain-containing protein tyrosine phosphatase 2, which inhibits phosphorylation induced by activation signals. Thus, binding of HSV glycoprotein B to PILR-α on RPE cells may inhibit the immune response. It has also been found that RPE cells play a role in the immune privilege of the subretinal space; hence, HSV infection of the RPE can further suppress immunity and cause greater infection.

The inflammatory cytokines that have been described to be produced in acute retinal necrosis, especially TNF-α, IFN-γ, and IL-4, may allow for granulomatous inflammation and the funduscopic findings characteristic of ARN.

Future studies should analyze potential receptors localized to the basolateral surfaces of RPE cells because infection from that side has been noted in vitro, although Bruch’s membrane may serve as a physical barrier to this in vivo. Additionally, the specific role of nectin-1, HVEM, and PILR-α in vivo can now be determined given that their roles in viral entry have been demonstrated. Much work still must be done for a full understanding of viral pathogenesis in the retina, yet our study...
elucidates unique insights that may provide therapies to control retinal infection and to preserve sight.

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