Differential effects of glycoprotein B epitope-specific antibodies on human cytomegalovirus-induced cell–cell fusion

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Attachment of, and cell–cell fusion induced by, human cytomegalovirus were studied in the presence of neutralizing monospecific antibodies against antigenic domains 1 (AD-1) or 2 (AD-2) of glycoprotein B (gB, gpUL55). Efficient inhibition of the virion-mediated fusion event was consistently observed for the human AD-2-specific antibody as determined by a reporter gene activation assay based on permissive astrocytoma cells. In contrast, antibodies directed against the major neutralizing gB epitope AD-1 reduced fusion only by 20–60 %. Virus attachment via heparan sulfate was unaffected by the antibodies under the conditions used. Virus receptor binding as examined by heparin treatment of adsorbed virus was significantly reduced only if the virus had been coated with the AD-2-specific antibody. Neutralization of virus infectivity by the AD-2-specific antibody thus seems most likely to result from interference with a receptor-binding event during initial virus–host cell interaction.

Glycoprotein B (gB) is an abundant component of the envelope of human cytomegalovirus (HCMV) and a major target of neutralizing antibodies that develop after natural infection (Britt et al., 1990; Gonczol et al., 1991; Marshall et al., 1992). Three antibody-binding sites have been mapped on the gB molecule, which is a type I transmembrane protein: the extracellular immunodominant antigenic domain 1 (AD-1) is located between amino acids 552 and 635; AD-2 (aa 50–86) at the N terminus is composed of two sites, aa 50–54 (site I) and 67–86 (site II); and AD-3 is located between aa 798 and 805 (Silvestri et al., 1991; Meyer & Radsak, 2000) at the extreme cytoplasmic C terminus. Of the three domains, only AD-1 and site II of AD-2 have been shown to induce virus-neutralizing antibodies (Kniess et al., 1991; Meyer et al., 1992; Wagner et al., 1992).

HCMV infection requires viral envelope glycoproteins and the respective cellular receptors to engage in a series of interactions, ultimately resulting in fusion of the viral envelope with the plasma membrane. The mechanisms by which gB-specific antibodies interfere with the complex processes involved leading to loss of viral infectivity have not been precisely defined so far, although a previous report suggested that antibodies may neutralize infection before or after adsorption to the cell surface (Ohizumi et al., 1992). In order to analyse further antibody-mediated HCMV neutralization – an activity with potential therapeutic and protective function in vivo – the effects of human monoclonal antibodies (mAbs) against AD-1 and AD-2 of HCMV gB on virus attachment as well as on virus-induced cell–cell fusion were investigated. Virus induced cell–cell fusion was measured by a new reporter gene activation assay (Gicklhorn et al., 1999) based on two stably transfected astrocytoma cell lines, U373-CAT and U373-VP16, in which induction of the chloramphenicol acetyltransferase (CAT) gene is triggered on experimentally induced cell–cell fusion by the transactivator GAL4-VP16. For the fusion assay, U373-CAT and U373-VP16 cells were seeded at a ratio of 1:1 in Dulbecco’s modified Eagle’s medium (DMEM) supplemented with 10 % foetal calf serum (FCS) into 15 mm dishes to obtain a subconfluent monolayer the next day (2 × 10⁵ cells). To induce cell–cell fusion, cell-free HCMV strain AD 169, grown and titrated on human foreskin fibroblasts (HF) as previously described (Eggers et al., 1992), was routinely used at an m.o.i. of 0-5. Higher m.o.i.s were previously found to result in reduced CAT activity, most likely as a result of pronounced cytotoxicity (Gicklhorn et al., 1999).

The neutralizing gB AD-1-specific mAbs ITC48, ITC52, ITC63B, or the AD-2-specific mAb ITC88 (recognizing site II of AD-2) and the non-neutralizing AD-1-specific mAb ITC39, as control antibody, were used (Ohlin et al., 1993) after standard ammonium sulfate precipitation and dialysis against PBS. Human IgG was quantified with a human IgG–Fc ELISA Quantification kit (NatuTec) according to the manufacturer’s instructions. For routine fusion-inhibition experiments, the virus inoculum was incubated with the
respective mAb (6.2 μg IgG ml⁻¹ each, diluted in DMEM) for 60 min at 37 °C. This concentration was selected as it is within the range of concentrations of AD-1-specific antibodies seen in vivo (Ohlin et al., 1997). As negative and positive controls, a human anti-pp65 mAb (MO58) (Ohlin et al., 1991) and an HCMV-positive human serum, respectively, were used. To obtain a baseline for the fusion process, virus was preincubated without antibody. Co-cultivated U373-CAT/VP16 cells were incubated with 200 μl of virus/antibody mixture for 60 min at room temperature to allow virus adsorption. The inoculum was removed and culture medium (DMEM supplemented with 2% heat-inactivated FCS) was added. At 48 h post-infection, cell monolayers were solubilized in 50 μl 1× lysis buffer (Promega) and analysed for CAT activity according to a standard protocol (Gorman et al., 1982). Since total cell-free virus preparations were used, the possibility that dense bodies and non-infectious enveloped particles contributed to the observed fusogenic activity (Schmolke et al., 1995) in addition to virions cannot be ruled out.

Efficient fusion inhibition by the standard IgG concentration (6.2 μg IgG ml⁻¹) was obtained for the human control serum as well as for the neutralizing AD-2-specific mAb ITC88, whereas with AD-1-specific antibodies (ITC52, ITC48, ITC63B) only 20–60% fusion inhibition was found (Fig. 1). Since all of these antibodies exhibited neutralizing activities (Ohlin et al., 1993), this result underlines the relevance of AD-2 for the fusion process. HCMV-mediated cell–cell fusion was unaffected by the control mAb MO58 as well as by non-neutralizing mAb ITC39.

The observed inhibitory effects suggested that the gB-specific mAbs interfered with the HCMV–cell interaction either at the level of binding to cellular surface receptors and/or with the consecutive fusion event. Initial attachment of HCMV to permissive host cells is dependent on the presence of cell-surface heparan sulfate proteoglycans (HSPGs) and can be competed by heparin (Compton et al., 1993). HCMV gB and primarily glycoprotein complex II of the HCMV envelope (Kari & Gehrz, 1992, 1993) have been shown to mediate interaction with cell-surface HSPGs. With regard to virus binding, in particular via the gB protein, an additional heparin-independent receptor binding has been postulated (Boyle & Compton, 1998).

Subsequent experiments were thus designed to examine whether the observed inhibitory effect of gB-specific mAbs occurred at the level of virus attachment or at a later stage. To allow accurate comparisons, identical numbers of cells, inoculum volume and proportion of virus and antibody were used. Radioactively labelled [³⁵S]AD 169 was prepared and titrated in HF cultures after purification by sucrose cushion ultracentrifugation as previously described (Eggers et al., 1992; Compton et al., 1993). HCMV inoculums and mAbs were preincubated for 60 min at 37 °C prior to inoculation of duplicates of co-cultivated U373-CAT/VP16 cells and incubation for 90 min at 4 °C. As negative controls, heparin-sodium (Serva) at 100 IU ml⁻¹ in DMEM was added for 60 min at 4 °C before addition of virus or during virus adsorption. The virus inoculum was removed and the cells were washed three times with PBS followed by lysis in lysis buffer (1% Triton X-100, 1% SDS in PBS). Cell extracts were prepared for scintillation counting (LS1801; Beckmann) as previously described (Radsak et al., 1985).

Attachment of HCMV in the presence of heparin was strongly inhibited, whereas for mAbs ITC48, ITC52 and ITC39 and control mAb MO58, an increased attachment was observed compared with the positive control (virus without mAb) (Table 1). This enhancement of infectivity most likely reflects a phenomenon described mainly for neutralizing mAbs called antibody enhancement of infectivity (Dimmock, 1993). Attachment in the presence of heparin-sodium (Serva) at 100 IU ml⁻¹ in DMEM was observed compared with the positive control (virus without mAb) (Table 1). This enhancement of infectivity most likely reflects a phenomenon described mainly for neutralizing mAbs called antibody enhancement of infectivity (Dimmock, 1993). Attachment in the presence of mAb ITC88 and ITC63B was slightly reduced by 4–8%. This minor effect, in particular for mAb ITC88, did not correlate with the strong inhibition observed in the fusion assay. Loss of infectivity of HCMV in the presence of AD-1-specific mAbs and AD-2-specific mAb ITC88 at concentrations of 6.2 μg IgG ml⁻¹ appeared therefore to result primarily from inhibition of virus–cell fusion mechanisms and not from interference with HCMV attachment to HSPGs. This finding agrees with a previous report suggesting that another AD-2-specific antibody blocks virus penetration but not virus attachment to the cell surface (Ohizumi et al., 1992),
and also extends such findings to AD-1-specific human antibodies. Inhibition of attachment at higher IgG concentrations, however, cannot be excluded but was not considered relevant in this context.

To distinguish further between primary HSPG binding and specific heparin-independent receptor binding, dissociation of bound HCMV (in the presence of mAbs) by heparin was measured. Co-cultivated U373-CAT/VP16 cells in duplicate were incubated for 90 min at 4 °C with radioactive virus/antibody mixtures (m.o.i. = 0.5) as described above to allow attachment. Unattached virus was removed by extensive washing with PBS before cells were washed with 200 μl of heparin solution (100 μg ml⁻¹) for 1 h at 4 °C to dissociate (heparin-soluble) virus that was most likely only attached to HSPGs. Radioactive virus remaining adherent to the cell monolayers at 4 °C was solubilized by detergent treatment and defined as heparin resistant.

In the presence of the control mAb MO58 or the AD-1-specific mAbs ITC52 or ITC63B, heparin-resistant receptor binding of HCMV did occur and was enhanced by up to 20 %, whereas the AD-2-specific mAb ITC88 reduced heparin-resistant receptor binding by 30 % (Fig. 2). These results suggested that the neutralizing activity of AD-1- and AD-2-specific mAbs may involve different stages of the virus adsorption process to cells.

**Table 1. Attachment of HCMV AD 169 in the presence of gB-specific mAbs**

<table>
<thead>
<tr>
<th>mAb</th>
<th>Virus attachment (%)</th>
<th>Expt 1</th>
<th>Expt 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Heparin</td>
<td>5 ± 0.1</td>
<td>11 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>− mAb</td>
<td>100 ± 1.6</td>
<td>100*</td>
<td></td>
</tr>
<tr>
<td>+ ITC52</td>
<td>113 ± 4.2</td>
<td>125 ± 23.4</td>
<td></td>
</tr>
<tr>
<td>+ ITC88</td>
<td>96 ± 5.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ ITC48</td>
<td>107 ± 5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ ITC63B</td>
<td>92 ± 3.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ ITC39</td>
<td>105 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ MO58</td>
<td>121 ± 0.1</td>
<td>114 ± 4.5</td>
<td></td>
</tr>
</tbody>
</table>

*Single determination.

Taken together, at the biologically relevant concentrations used, the inhibitory effect on HCMV-mediated cell–cell fusion by the AD-2-specific mAb exceeded that by AD-1-specific mAbs. Furthermore, none of the antibodies affected virus attachment via HSPGs under the conditions used. This observation is in contrast to that of Silvestri & Sundqvist (2001) who determined HSPG binding of AD-2 using a synthetic AD-2 peptide. Inhibition of HCMV-specific fusion by the AD-2-specific mAb exceeded that by AD-1-specific mAbs. The reduced heparin-resistant receptor-binding in the presence of mAb ITC88 may either result from blocking the receptor binding domain of HCMV gB directly or may be an indirect consequence of antibody binding, which may induce a conformation of the gB molecule that is no longer competent to interact with the putative cellular receptor. Interestingly, in the case of herpes simplex virus 1 glycoprotein D, the neutralizing activity of group Ib mAbs was suggested to reflect an overlap between the epitopes recognized and the receptor-binding domain (Whitbeck et al., 1999). Investigations are therefore under way to elucidate whether the AD-2 epitope of HCMV gB also overlaps the receptor-binding domain of gB.

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