Immunohistochemical staining for ganglioside GD1b as a diagnostic and prognostic marker for primary human brain tumors

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Immunohistochemical staining intensity for ganglioside GD1b was determined for 108 human neuroectodermal tumors. Most of the tissue elements that immunostained were tumor cells; only a few axons and occasional neurons reacted in some specimens. All pilocytic astrocytomas stained very positively, whereas none of the ependymomas and only 11% of primitive neuroectodermal tumors, 20% of glioblastomas, and 28% of anaplastic astrocytomas showed more than faint staining. A similar association between grade and immunostaining was seen in tumors containing an oligodendroglial component, but reactivity was not as strong as in astrocytic tumors or primitive neuroectodermal tumors. Results of Cox regression showed significant associations between immunostaining intensity and survival for all cases taken together (P = 0.007); for the group consisting of astrocytomas, oligoastrocytomas, and oligodendroglial (P = 0.002); and for astrocytomas alone (P = 0.04). Results were also significant using a proportional hazards model controlling for patient age (all cases P = 0.005; astrocytomas only P = 0.02), but not when controlling for tumor grade. Our results indicate that immunohistochemical staining for GD1b is correlated with tumor grade and that it may be of prognostic utility in some primary human brain tumors, especially astrocytomas. Neuro-Oncology 1, 261–267, 1999 (Posted to Neuro-Oncology [serial online], Doc. 98-27, September 9, 1999. URL <neuro-oncology.mc.duke.edu>)

Systems of classification and grading of human gliomas are currently based on their histologic features. Within each category and grade, gliomas with classic features are easily recognized. Within all categories and grades, however, there are ranges of histologic appearance, the aspects of which may merge imperceptibly, being sometimes placed in one category or grade, and sometimes in another. Thus, a diagnosis often rests upon the subjective interpretation of clusters of histologic features about which even experts can disagree. For this reason, considerable effort has been expended to identify diagnostic and prognostic molecular markers of greater objectivity in glioma diagnosis.

Gangliosides are sialic acid-containing complex glycosphingolipids present in all mammalian tissues studied to date and are potentially useful in tumor diagnosis. Gangliosides are classified according to the sequence and linkages of neutral sugars, amino sugars, and sialic acids in the oligosaccharide portion of the molecule (Ledeen and Yu, 1982). The oligosaccharide is synthesized in the Golgi complex, with several metabolic pathways leading to different families of gangliosides that are named (Chester, 1998; Svennerholm, 1980) on the basis of their oligosac-
charide sequences (Table 1). One of the major families of gangliosides in normal adult brain, the “1b” family, is derived from a parent compound called GD1b. The latter accounts for most of the 1b family gangliosides in normal human brain (Vanier et al., 1971). The other major 1b gangliosides in human brain include GT1b, which has one sialic acid attached to the GD1b structure, and GQ1b, which has two additional sialic acids (Wiegandt, 1982). A consistent finding in studies of gangliosides in human astrocytomas is a shift in the pattern of gangliosides, resulting in a relative loss of those with complex oligosaccharides and an increase in those that have simpler oligosaccharides (Bera et al., 1985; Fredman et al., 1988; Jennismann et al., 1990; Kostic and Bucheit, 1970; Sung et al., 1993; Traylor and Hogan, 1980). In previous studies, we found that loss of the 1b gangliosides was associated with higher histologic grade and poorer survival (Sung et al., 1993; 1994). There were two possible interpretations of this finding. One was that, within the lower grade gliomas, the 1b gangliosides are located within tumor cells, but those gangliosides are not expressed in the higher grade tumors. The other interpretation was that the loss of 1b gangliosides from the higher grade tumors is simply due to destruction by invading tumor cells of nonneoplastic cellular elements normally containing 1b gangliosides. The present study was designed both to resolve this issue and to determine whether an immunohistochemical assay for the major 1b ganglioside in brain (GD1b) could help in the classification, grading, and prognosis of human gliomas.

### Methods

#### Tumor Tissues

Tumor samples were obtained from patients within 30 min of surgical removal, examined grossly, and divided into pieces for diagnostic and research purposes. Those samples intended for immunohistochemical staining were snap frozen by placing the tissue in a cryomold (Tissue-Tek, Miles Inc., Elkhart, Ind.) filled with OCT (Sandon, Pittsburgh, Penn.) and immersing it into isopentane (2-methyl butane, Fisher Scientific, N.J.) in the vapor phase of liquid nitrogen. The histologic diagnoses and grades assigned represented the majority opinions of three neuropathologists (B.W.S., P.C.B., and A.J.Y.), who independently reviewed hematoxylin and eosin-stained sections that had been formalin fixed, routinely processed, and paraffin embedded.

### Immunohistochemical Procedure

Tissues were sectioned on a cryostat (–20°C) at 5-µm thickness and placed on Superfrost Plus slides (Fisher Scientific, Pittsburgh, Penn.). For each sample three sections were cut: one for the assay, another as a negative control, and the last for a hematoxylin and eosin stain as a control for tumor content. After the slides were air dried, they were fixed in cold acetone at –20°C for 3–4 min, allowed to dry for 2 h, and rehydrated with 0.05 M Tris-HCl (pH = 7.6, TBS) for 4 min at room temperature. Non-specific binding was blocked with 10% normal horse serum (Vector Labs, Burlingame, Calif.) for 30 min at room temperature. Primary antibody GGR12 (Ozawa et al., 1992) was added undiluted, and the sections were incubated in a humid chamber overnight at 4°C (average 16–18 h). As a negative control, a similar isotype antibody (mouse IgG2b, Dako, Carpinteria, Calif.) was used at a 3-µg/ml concentration. Primary and control antibodies were removed and the slides washed in TBS for 4 min. The secondary antibody (horse antimouse biotin conjugated) was then applied at a dilution of 1:200 (2–4 µg/ml) in a 2% normal horse serum in TBS for 30 min at room temperature in a moist chamber before being washed in TBS for 4 min. Endogenous peroxidase activity was blocked with a 2.25% peroxide in methanol solution for 30 min at room temperature and washed; avidin-biotin complex horseradish peroxidase (Vector Elite Kit, Burlingame, Calif.) was added for 30 min at room temperature. The samples were then washed in TBS and placed into a 0.02 M acetate buffer for 5 min before transfer into 3-amino-9-ethylcarbazole. The reaction was started by adding 20 ml of a 3% hydrogen peroxide solution to the 3-amino-9-ethylcarbazole substrate.

### Table 1. Ganglioside structure and most commonly used systems of nomenclature

<table>
<thead>
<tr>
<th>Ganglioside Structure</th>
<th>IUPAC-IUB</th>
<th>Schematic Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM3</td>
<td>II°NeuAc-lacCer</td>
<td>NeuAcα2→3Galβ1→4Glcβ1→1Cer</td>
</tr>
<tr>
<td>GM2</td>
<td>II°NeuAc-GgOse_cer</td>
<td>GalNAcβ1→4(NeuAcα2→3)Galβ1→4Glcβ1→1Cer</td>
</tr>
<tr>
<td>GM1, GM1a</td>
<td>II°NeuAc-GgOse_cer</td>
<td>Galβ1→3GalNAcβ1→4(NeuAcα2→3)Galβ1→4Glcβ1→1Cer</td>
</tr>
<tr>
<td>GM1b</td>
<td>IV°NeuAc-GgOse_cer</td>
<td>NeuAcα2→3Galβ1→3GalNAcβ1→4Galβ1→4Glcβ1→1Cer</td>
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<tr>
<td>GD3</td>
<td>II°(NeuAc)_2-lacCer</td>
<td>NeuAcα2→8NeuAcα2→3Galβ1→4Glcβ1→1Cer</td>
</tr>
<tr>
<td>GD1a</td>
<td>IV°NeuAc, II°NeuAc-GgOse_cer</td>
<td>NeuAcα2→3Galβ1→3GalNAcβ1→4(NeuAcα2→3)Galβ1→4Glcβ1→1Cer</td>
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<tr>
<td>GD2</td>
<td>II°(NeuAc)_2-GgOse_cer</td>
<td>GalNAcβ1→4(NeuAcα2→8NeuAcα2→3)Galβ1→4Glcβ1→1Cer</td>
</tr>
<tr>
<td>GD1b</td>
<td>II°(NeuAc)_2-GgOse_cer</td>
<td>Galβ1→3GalNAcβ1→4(NeuAcα2→8NeuAcα2→3)Galβ1→4Glcβ1→1Cer</td>
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<tr>
<td>GT1b</td>
<td>IV°NeuAc, II°(NeuAc)_2-GgOse_cer</td>
<td>NeuAcα2→3Galβ1→3GalNAcβ1→4(NeuAcα2→8NeuAcα2→3)Galβ1→4Glcβ1→1Cer</td>
</tr>
<tr>
<td>GQ1b</td>
<td>IV°(NeuAc)_2, II°(NeuAc)_2-GgOse_cer</td>
<td>NeuAcα2→8NeuAcα2→3Galβ1→3GalNAcβ1→4(NeuAcα2→8NeuAcα2→3)Galβ1→4Glcβ1→1Cer</td>
</tr>
</tbody>
</table>

*Svennerholm, 1980.*

*Chester, 1998.*
and coloration was allowed to develop for 16 min at room temperature. The slides were then washed briefly with acetate buffer, placed under warm tap water for 5 min, counterstained with Gill’s #1 solution (Fisher Scientific, N.J.) for 1 min, washed with tap water, fixed briefly with 0.01 M Tris (pH = 9.5), washed with double distilled water, and coverslipped with warmed glycerin jelly.

Staining Intensity

Two investigators (T.C.C. and A.J.Y.) independently examined the slides and expressed the staining intensity on a 4-tiered scale. Staining intensity of the tumor samples was related to two controls run with each assay. Staining was 3+ when it was equivalent to the intensity of the staining observed in rat cerebral cortex. Tissue that was similar to the negative controls was considered to be 0 staining. Intermediate staining was considered to be either 1+ (mild) or 2+ (moderate). Interobserver agreement was over 90%; disagreements were resolved by subsequent simultaneous viewing through a double-headed microscope.

Ganglioside Analyses

Tissues were extracted first with chloroform/methanol/water (1:2:20%) and then with chloroform/methanol/water (1:1:5%). The supernatants were pooled and reconstituted in chloroform/methanol/water (30:60:8), after which acidic glycolipids were isolated using a DEAE-Sephadex column (Ledeen et al., 1973). Gangliosides were purified, separated using thin-layer chromatography, and quantitated using the methods described by Sung et al. (1994).

Results

A total of 108 tumors were examined immunohistochemically for GD1b. The number of tumors in each major diagnostic category is shown in Table 2. Pilocytic astrocytomas stained quite positively in both a cytoplasmic and surface pattern. In the few cases of glioblastoma multiforme that were positive, there was staining of both the scant cytoplasm and the surface membrane of tumor cells. Typical examples of positive staining in a pilocytic astrocytoma and a negative reaction in a glioblastoma multiforme are shown in Fig. 1. The distribution of staining intensities among the major diagnostic categories is shown in Table 2 and among the four grades of astrocytomas in Table 3. All of 11 pilocytic (grade 1) astrocytomas exhibited reactivities of either 2+ or 3+. Five of 7 anaplastic (grade 3) astrocytomas had either no staining or only 1+ staining of the tumor cells; as a rule most anaplastic regions were nonstaining. Of the 47 glioblastomas multiforme, 32 (68%) were negative and none had 3+ staining. Whereas 9 of 10 oligodendrogliomas and oligoastrocytomas (90%) stained 2+, fully 9 of 15 anaplastic oligodendrogliomas and anaplastic oligoastrocytomas (60%) stained either 1+ or were negative. Only 1 of 9 primitive neuroectodermal tumors and none of 7 ependymomas contained any immunopositive tumor cells. In all cases studied, positive immunostaining occurred mainly in the tumor cells; at most, only scant, infiltrated normal neural elements (axons and neurons) in the tumor tissue stained positively. This reflects the care that was taken at the time of tissue dissection to select portions of solid tumor.

To determine the validity of the immunohistostaining intensities, we plotted these semiquantitative values against the percentage of GD1b contained in the total amount of ganglioside, measured chemically, in fresh tissues of the same cases. These measurements will form the basis of a separate report. Fig. 2 shows that, for all tumors, regardless of diagnosis, there was a good correlation between these two estimates of GD1b content. Correlation was even better for the 52 astrocytomas studied (P < 0.005). However, in no group did tumors

<table>
<thead>
<tr>
<th>Staining intensity</th>
<th>Astrocytoma</th>
<th>Oligo</th>
<th>Anaplastic oligo</th>
<th>Ependymoma</th>
<th>PNET</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(63.6)</td>
<td>(0.00)</td>
<td>(9.09)</td>
<td>(12.7)</td>
<td>(14.5)</td>
<td>(100)</td>
</tr>
<tr>
<td>1</td>
<td>(64.3)</td>
<td>(7.14)</td>
<td>(28.6)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(100)</td>
</tr>
<tr>
<td>2</td>
<td>(50.0)</td>
<td>(32.1)</td>
<td>(14.3)</td>
<td>(0.00)</td>
<td>(3.57)</td>
<td>(100)</td>
</tr>
<tr>
<td>3</td>
<td>(81.8)</td>
<td>(0.00)</td>
<td>(18.2)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(100)</td>
</tr>
<tr>
<td>Total</td>
<td>(62.0)</td>
<td>(9.26)</td>
<td>(13.9)</td>
<td>(6.48)</td>
<td>(8.33)</td>
<td>(100)</td>
</tr>
</tbody>
</table>

Abbreviations: Oligo, oligodendroglioma; PNET, primitive neuroectodermal tumor.

Numbers in bold are the number of cases. Numbers in the top parentheses are percentage of tumors expressing a particular staining intensity for GD1b (percent of row). Numbers in the bottom row of parentheses are the percentage of specific tumor types expressing a particular staining intensity for GD1b (percent of column).

*A staining intensity of 0 is equivalent to negative control. A staining intensity of 3 is equivalent to positive control (rat cerebral cortex).
with intensities 1+ and 2+ separate well. Thus for this data set, no information would be lost in using an alternative 3-tiered system that combines 1+ and 2+ into a single intermediate group. An analysis of variance (ANOVA) comparing the percentages of GD1b in a 3-tiered system showed that the staining intensity levels were all significantly separated using the least significant difference post hoc test (low to intermediate, \( P = 0.005 \); intermediate to high, \( P = 0.06 \); low to high, \( P = 0.0004 \)).

Taking all cases together, we found a significant \( (P = 0.007) \) association between intensity of immunostaining for GD1b and survival of patients in a univariate analysis using the Logrank test (Fig. 3). Similar results were obtained when analyzing data inclusive of astrocytomas, oligoastrocytomas, and oligodendrogliomas \( (P = 0.001) \) (Fig. 4), as well as data limited to astrocytomas \( (P = 0.04) \) (Fig. 5). Results were also significant in the multivariate analyses controlling for patient age with the Cox proportional hazards regression method (all cases, \( P = 0.004 \); astrocytoma plus oligoastrocytoma plus oligodendroglioma cases, \( P = 0.02 \); astrocytomas only, \( P = 0.02 \)). Using Cox regression, however, we found no significant difference when tumor grade was also added into the model.

Table 3. Frequency of staining intensities for all grades of astrocytoma

<table>
<thead>
<tr>
<th>Staining intensity(^a)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>(0.00)</td>
<td>(2.86)</td>
<td>(5.71)</td>
<td>(91.4)</td>
<td>(100)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>(0.00)</td>
<td>(50.0)</td>
<td>(28.6)</td>
<td>(68.1)</td>
<td>(52.2)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(33.3)</td>
<td>(66.7)</td>
<td>(100)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(42.9)</td>
<td>(12.8)</td>
<td>(13.4)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>(16.4)</td>
<td>(2.99)</td>
<td>(10.4)</td>
<td>(70.1)</td>
<td>(100)</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: Oligo, oligodendroglioma; PNET, primitive neuroectodermal tumor.

Numbers in **bold** are the number of cases. Numbers in the top parentheses are percentage of tumors expressing a particular staining intensity for GD1b (percent of row). Numbers in the bottom row of parentheses are the percentage of specific tumor types expressing a particular staining intensity for GD1b (percent of column).

\(^a\) A staining intensity of 0 is equivalent to negative control. A staining intensity of 3 is equivalent to positive control (rat cerebral cortex).
Histologic grading of astrocytomas and oligodendrogliomas is based on the expression of several of the features of anaplasia. Early methods included those of Kernohan et al. (1949) and Ringertz (1949), who described four- and three-tiered systems, respectively, for grading astrocytomas. These were subjective in nature and were based on finding a composite of several of these features. Daumas-Dupont proposed a more objective system for grading astrocytomas in which the presence or absence of four histologic features (nuclear atypia, mitotic figures, endothelial proliferation, and necrosis) were determined; the number of positive features were totaled to generate a grade (Daumas-Dupont, 1992; Daumas-Dupont et al., 1988). Referred to as the St. Anne-Mayo method, this system correlates quite well with the survival of patients with diffuse or fibrillary astrocytomas. In the World Health Organization’s classification of CNS tumors, pilocytic astrocytoma is considered to be grade I on the basis of its biological behavior (Kleihues et al., 1993, p. 112). However, pilocytic astrocytomas may show histologic features, such as occasional mitotic figures, vascular proliferation, and necrosis, which in fibrillary astrocytomas would increase the grade to III or even IV. This accounts for the frequency with which some low-grade tumors are misdiagnosed as high-grade (Finlay et al., 1995). Therefore, it is critically important to identify pilocytic astrocytomas so the St. Anne-Mayo or World Health Organization grading system is not inappropriately applied. The availability of a marker that would aid in the identification of pilocytic astrocytomas would be extremely useful, especially to pathologists less familiar with this entity. In our study, all 14 pilocytic astrocytomas immunostained either 2+ or 3+ for GD1b.

In contrast, no glioblastomas multiforme stained 3+, and fully 84% showed only faint reactivity or no reactivity at all. Unfortunately, staining of anaplastic astrocytomas was distributed across all levels of intensity.

There are changes in the ganglioside composition of normal human brain with development and aging. On the basis of ganglioside sialic acid, the proportion of total ganglioside accounted for by GD1b progressively increases from approximately 10% at birth to 30% in adults (Segler-Stahl et al., 1983; Vanier et al., 1971). This is the inverse of what we found for the relation between

![Fig. 2. Correlation between chemical and immunohistochemical estimates of GD1b in tumors. The box plot shows GD1b as a percent of total gangliosides determined chemically versus the intensity of immunohistochemical staining for GD1b. The box frames the upper and lower quartiles. The whiskers show the range of the contiguous data. Outliers are displayed individually. The shaded regions give a 95% confidence interval for the median.](https://academic.oup.com/neuro-oncology/article-abstract/1/4/261/1042039)

![Fig. 3. Relationship between staining intensity and survival for all cases studied. Survival data were available for 8 of 11 patients whose tumors stained at level 3 intensity (1 of 8 patients died); for 25 of 28 patients whose tumors stained at level 2 intensity (7 of 25 died); for 13 of 14 patients whose tumors stained at level 1 intensity (5 of 13 died); and for 52 of 55 patients whose tumors stained at level 0 intensity (38 of 52 died).](https://academic.oup.com/neuro-oncology/article-abstract/1/4/261/1042039)

![Fig. 4. Relationship between staining intensity and survival for astrocytomas, oligoastrocytomas, and oligodendrogliomas. Survival data were available for 8 of 11 patients whose tumors stained at level 3 intensity (1 of 8 patients died); for 24 of 27 patients whose tumors stained at level 2 intensity (7 of 24 died); for 13 of 14 patients whose tumors stained at level 1 intensity (5 of 13 died); and for 37 of 40 patients whose tumors stained at level 0 intensity (33 of 37 died).](https://academic.oup.com/neuro-oncology/article-abstract/1/4/261/1042039)}
Eight of the nine primitive neuroectodermal tumors were unreactive with the GD1b antibody, which confirms the general unreaction between low GD1b immunostaining and high-grade CNS neoplasia. Although making the correct diagnosis of primitive neuroectodermal tumor is usually not a problem, positive immunostaining for GD1b in what appears to be a poorly differentiated primary tumor of the CNS should caution one against this diagnosis.

One interesting finding of our study is that GD1b was detected within tumor cells. Indeed, in the tumor tissues we examined, the vast majority of immunostaining for GD1b was within tumor cells. Although occasionally there was some immunopositivity in elongate structures that might have been axons, this could account for only a small amount of the total GD1b within the tissues. The animal studies of Seyfried and colleagues were interpreted to indicate that a significant proportion of the glycolipid in glioma tissues they studied was present in lymphocytes and macrophages infiltrating the tumor (El-Abbadi and Seyfried, 1994; Seyfried et al., 1996). However, GD1b is not a major component of lymphoid or myeloid cells, so the finding of glycolipids of this type could not be attributed to infiltration by such cells.

In conclusion, our results demonstrate that immunostaining for GD1b gives a reasonably accurate estimate of the GD1b content of gliomas. In pilocytic astrocytomas, tumors known for their relatively solid, noninfiltrative nature, most of the GD1b is in the tumor cells rather than in residual neuronal elements. Because fibrillar astrocytomas and oligodendrogliomas of higher grade exhibit little or no staining for GD1b, immunoreactivity for this glycolipid may be useful in establishing their histologic grade.

References


Jennemann, R., Rodden, A., Bauer, B.L., Mennel, H.D., and Wiegandt, H.