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BACKGROUND AND PURPOSE: The diagnosis of gliomatosis cerebri with MR imaging is known to be difficult. We report on the value of MR spectroscopy in the diagnosis, grading, and biopsy planning in eight patients with histopathologically proved gliomatosis cerebri.

METHODS: Patients underwent MR imaging and MR spectroscopy (single-voxel point-resolved spectroscopy [PRESS] at 1500/135, and chemical-shift imaging [CSI] PRESS at 1500/135) before open (n = 4) or stereotactic (n = 4) biopsy. In six patients who underwent CSI, biopsy samples were taken from regions of maximally elevated levels of choline/N-acetylaspartate (Cho/NAA).

RESULTS: All patients showed elevated Cho/creatine (Cr) and Cho/NAA levels as well as varying degrees of decreased NAA/Cr ratios, which were most pronounced in the anaplastic lesions. In low-grade lesions, there was a maximum Cho/NAA ratio of 1.3, whereas in anaplastic tumors, the maximum Cho/NAA level was at least 2.5. Spectra in two patients with grade III lesions revealed a lactate peak; lactate and lipid signals were seen in two patients with grade IV lesions. Biopsy specimens from regions with maximally elevated levels of Cho/NAA showed dense infiltration of tumor cells.

CONCLUSION: MR spectroscopy might be used to classify gliomatosis cerebri as a stable or a progressive disease indicating its potential therapeutic relevance.

Gliomatosis cerebri is a rare brain tumor characterized by a diffuse neoplastic overgrowth of glial elements and extensive infiltration of at least two lobes (1). The neuronal architecture is usually preserved except in areas where the infiltration becomes very dense (2). Gliomatosis cerebri was first described by Nevin in 1938 (3) and, to date, fewer than 200 cases have been reported in the literature. MR imaging is the radiologic method of choice (4), but MR findings are often nonspecific and underestimate the extent of the lesion (5). Moreover, since the area of most extensive anaplasia determines the clinical course of the disease (6), it is important to define these targets before biopsy. The purpose of this study was to characterize the metabolic features of gliomatosis cerebri and to evaluate MR spectroscopy in the grading and biopsy planning of gliomatosis.

Methods

Eight patients (one woman and seven men, ages 10–67 years; mean age, 42 years) were examined on a 1.5-T MR scanner. MR imaging included T1-weighted sequences before and after injection of contrast material and T2-weighted sequences in all patients. Additionally, the fluid-attenuated inversion-recovery (FLAIR) sequence was applied in five patients. In all patients, the MR spectroscopy protocol consisted of single-voxel point-resolved spectroscopy (PRESS) with a voxel size of 15 to 25 mm³ and imaging parameters of 1500/135,270/128 (TR/TE/acquisitions) within the area of hyperintensity on T2-weighted images as well as in the margin of the lesion and, in cases with unilateral involvement, in the corresponding area of the contralateral, unaffected hemisphere. None of the patients who underwent only single-voxel spectroscopy had bilateral involvement. Additionally, chemical-shift imaging (CSI) with parameters of 1500/135/2 was used in six patients. The CSI voxel size was 7.5 × 7.5 × 15 mm. All data postprocessing was performed with software provided by the manufacturer. Spectral postprocessing included 4k zero-filling, gaussian apodization, Fourier transformation, water reference processing, frequency shift correction, and phase and baseline correction. Peak integral values were determined by a curve fit algorithm at 3.0 ppm for creatine (Cr), 3.2 ppm for choline-containing compounds (Cho), 1.35 for lactate, and 2.0 ppm for N-acetylaspartate (NAA). Peak integral values were normalized to the internal Cr peak.

Histopathologic diagnosis was confirmed by open (n = 4) or stereotactic (n = 4) biopsy. In six patients who underwent CSI, localizer images of the areas of maximally elevated Cho/NAA levels were given to the neurosurgeon, who performed a targeted biopsy of this area. These biopsies were not taken additionally to the requisite specimen for histopathologic di-
agnosis. In two patients who underwent single-voxel spectroscopy only, biopsy specimens were taken from brain tissue in the area corresponding to the voxel. A postoperative CT study was performed in all patients to ensure that the biopsy sample was taken from the intended location.

**Representative Case Reports**

**Case 4**

A 38-year-old woman presented with a short history of visual disturbance. The clinical examination revealed a visual acuity of 2/5 in the right eye. CT studies showed extensive areas of hypodensity in both hemispheres with little mass effect. MR images depicted diffuse T2 hyperintensities in both frontal and parietal lobes and a thickening of the optic chiasm (Fig 1A). There was no contrast enhancement after injection of gadopentetate dimeglumine. MR spectroscopy revealed a mild increase in the Cho/Cr and Cho/NAA ratios and a decrease in the NAA/Cr ratio (Fig 1B). Lactate or lipids were not found. A targeted biopsy sample was taken from the area with the maximally elevated Cho/NAA level with a value of 1.1 and revealed a grade II lesion (lesion grades are in accordance with the World Health Organization [WHO] classification scheme).

**Case 5**

A 12-year-old boy presented after experiencing the first instance of a generalized seizure. The MR examination revealed extensive areas of hyperintensity on T2-weighted images affecting the cortex, white matter, and basal ganglia of the right hemisphere with little mass effect (Fig 2A). No enhancement was seen after injection of contrast material. Single-voxel MR spectroscopy and CSI revealed a marked increase of Cho/Cr and NAA/Cr and lactate in some parts of the lesion (Fig 2B).
Targeted open biopsy was performed and, owing to the pronounced proliferative activity, the specimen was classified as a grade III lesion. The boy rapidly deteriorated, and focal neurologic signs developed. Despite radiotherapy, he died 20 months after the first symptoms appeared.

Case 8

A 55-year-old man presented with a short history of lack of drive and depression; a diagnosis of an endogenous depression was made. Because his symptoms rapidly worsened, a CT study was performed, which showed bifrontal areas of hypointenation. MR images exhibited an infiltration of both hemispheres, predominantly in the frontal lobes with involvement of the corpus callosum (Fig 3A). MR spectroscopy showed extensive elevation of the Cho/Cr and Cho/NAA levels and a decrease in the NAA/Cr ratio (Fig 3B). In some parts of the lesion, especially in the rostral corpus callosum, there were lipid signals at 0.8 to 1.3 ppm. A stereotactic biopsy was done in the area of the maximally elevated Cho/NAA level, with a value of 5.5 in the left frontal lobe. The histopathologic specimen was classified as a grade IV lesion.

Results

Clinical Findings

Clinical data are summarized in the Table. Considering the extent of tumor infiltration, patients had little symptomatology. In five patients, seizure was the initial neurologic symptom. Two patients (cases 4 and 6) had a short history of visual impairment due to infiltration of the chiasm and the optic nerves. One patient (case 8) presented with a short history of depression. The mean interval from symptom onset to diagnosis was 2 months (range, 1–9 months).

Imaging Findings

All patients had extensive areas of hyperintensity on T2-weighted images affecting at least two lobes (Fig 4), which appeared hypointense on T1-weighted images. The basal ganglia and the temporal and frontal lobes were affected in all patients. Additional infiltration of the parietal and occipital lobes was seen in five patients. Bilateral involvement was found in four patients. A typical finding in all pa-
patients was diffuse infiltration of the cortex with an
enlargement of the cortical sulci and poor demar-
cation of the gray and white matter. Two patients
had infiltration of the optic chiasm and the optic
nerves. The brain stem and the cerebellum were not
affected in any of our patients. Considering the ex-
tensive areas of signal abnormalities, there was
only moderate mass effect. Two patients (cases 7
and 8) displayed patchy areas of contrast enhance-
ment in the white matter on T1-weighted images.
Areas of cortical or leptomeningeal enhancement
were not found.

Spectroscopic Findings
All patients had elevated Cho/Cr and Cho/NAA
ratios as well as decreased NAA/Cr ratios of vary-
ing degrees within the areas of hyperintensity on
T2-weighted images (Figs 1–3). Anaplastic lesions
exhibited markedly higher maximal Cho/Cr and
Cho/NAA ratios and a lower NAA/Cr ratio (Fig 5).
The difference between low- and high-grade tu-
mors was most pronounced in the Cho/NAA ratio.
Patients with a grade II lesion had a maximum
NAA/Cho ratio of 1.3, whereas those with grade
III (Fig 2) and grade IV (Fig 3) gliomatosis had a
maximum value of at least 2.5, with no overlap
between high- and low-grade lesions (Fig 5). The
highest Cho/NAA ratio of 8.9 was found in a pa-
tient with grade IV gliomatosis. Lactate was found
in all high-grade lesions (Figs 2 and 3). Lactate was
differentiated from lipid signals by the inversion of
the lactate doublet at 135 milliseconds. In two pa-
tients (cases 7 and 8, with grade IV tumors), lipid
signals were found in some areas of the lesion. In
patients who underwent CSI, there was a moderate
elevation of Cho/Cr and a decrease of NAA/Cr in
regions in the margin of the lesion that appeared
normal on T2-weighted images.

Neuropathologic Findings
On slides stained with hematoxylin-eosin, the
cortex and adjacent white matter showed a diffuse
moderately dense infiltration of elongated tumor
cells with little destruction of the parenchyma. Mi-
totic figures were infrequent. On the basis of cell
density, cellular pleomorphism, frequency of mi-
tosis, and proliferative activity, the diffusely infl-
trating gliomas were categorized as grades II to III.
Two lesions (in patients 7 and 8) showed, in ad-
tion to the diffusely infiltrating pattern, a few ar-
eas with the typical morphology of glioblastoma
multiforme (grade IV). Targeted biopsy specimens
taken from areas with maximally elevated Cho/
NAA levels showed dense infiltration of neoplastic
cells in all cases. There was a close relationship
between anaplasia and extent of Cho/NAA in-
crease, with a maximum ratio of 1.3 in grade II
lesions and a minimum of 2.5 in grade III and IV
tumors (Fig 5).

Discussion
Gliomatosis cerebri is characterized by a diffuse
infiltration of neoplastic glial cells with preserva-
tion of neuronal architecture (3). In the latest WHO
classification it is listed as a subgroup of neuro-
epithelial tumors of uncertain origin with involve-
ment of at least two lobes without a cellular, cen-
trally necrotic center (1). However, there is still
debate as to whether gliomatosis cerebri is a his-
topathologic entity or just a heterogeneous group
of gliomas characterized by the tendency of wide-
spread infiltration (5, 7). Nevertheless, cytogenetic
findings point at a distinct chromosomal alteration
in gliomatosis cerebri as a distinguishing feature
from astrocytomas (8).
The antemortem diagnosis of gliomatosis cerebri
represents a differential diagnostic problem. The
clinical findings are nonspecific and, in relation to
the extent of the lesion, quite moderate. CT findings are either normal or show areas of hypoattenuation with little mass effect (4, 9–11). MR imaging has become the radiologic method of choice, because it reveals a more extensive involvement of the CNS and subtle changes, such as involvement of the cortex or the basal ganglia (10–14). However, the changes on MR images are nonspecific and the differential diagnosis includes ischemia, multiple sclerosis, encephalitis, leukodystrophies, and subacute sclerosing panencephalitis (11, 15). There are many reports of a delayed antemortem diagnosis of gliomatosis cerebri (16–21). Different imaging techniques, such as positron emission tomography (22) or single-photon emission CT (16, 23), have revealed nonspecific changes in gliomatosis cerebri and thus do not contribute much to the differential diagnosis. MR spectroscopy provides a noninvasive biochemical assay of normal and pathologic brain tissue. A number of previous studies have reported increased Cho/Cr and Cho/NAA ratios in tumors as compared with normal brain tissue (24–27), supposedly caused by a decrease of NAA, reflecting replacement of neurons by neoplastic glial cells (28), and an increase of Cho, caused by an increased membrane turnover in tumors (29). This particular spectroscopic pattern of neoplastic brain lesions has been used to differentiate brain tumors (30) or to establish prognostic parameters (31). All our patients had similar spectra, with a pronounced increase in Cho/Cr and decrease in NAA/Cr, consistent with a neoplastic lesion. Yet a small percentage of nonneoplastic lesions may have a “neoplastic” spectral pattern (eg, elevated Cho and decreased NAA and Cr), like encephalitis, demyelination, or organizing hemorrhage (32), which underlines the need for histopathologic examination as the standard of reference.

The grading of gliomatosis is of great importance in prognosis and possibly in therapy. Even in the case of suspected gliomatosis cerebri, correct histopathologic diagnosis may be difficult on the basis of a focal biopsy specimen of a diffuse process (14, 23, 33). Biopsy planning based solely on MR findings may be misleading, because MR imaging is unreliable in the grading of gliomas (34), making it difficult to designate the target for the biopsy. The extent of Cho/Cr and Cho/NAA increases has been used as an aid in the grading of gliomas (35). In patients with low-grade lesions (WHO grade II), we observed a moderate Cho/NAA ratio increase of up to 1.3, whereas anaplastic lesions exhibited a distinctly higher Cho/NAA increase of at least 2.5, with the maximum value of 8.9 in a grade IV tumor. Thus, the area of maximum Cho/NAA increase may be used to assess the overall tumor grade and also to determine a target for open or stereotactic biopsy, as has already been described for low-grade astrocytomas (36). Apart from highly elevated Cho/Cr and Cho/NAA ratios, the occurrence of lipids in tumors is indicative of a malignant lesion (37, 38). In all our patients with anaplastic gliomatosis (two with grade III tumors and two with grade IV tumors), there was a lactate doublet at 1.35 ppm that was not present in the low-grade lesions. The presence of lactate has been found to be a poor prognostic factor, independent of the histologic grade (39). This, however, is controversial, and even though lactate is more likely to be found in high-grade lesions, large studies have shown that lactate cannot be used as a reliable predictor of either malignancy or poor prognosis (37, 40).

Apart from being beneficial in the grading of gliomatosis cerebri, MR spectroscopy might reflect the true extent of neoplastic infiltration more accurately than MR imaging. Correlative studies have shown more extensive histopathologic involvement of the CNS than was expected on the basis of MR imaging findings (13, 15, 22, 41). In our patients, we observed elevated Cho/Cr and Cho/NAA ratios in the tumor margins that appeared normal on T2-weighted images. However, since we did not perform stereotactic biopsies of these regions, we do not have histopathologic proof of actual tumor invasion in these areas. In most of our patients we performed both single-voxel MR spectroscopy and CSI. In our view, single-voxel spectroscopy is suitable for a quick metabolic characterization of a lesion but it is unable to show spatial diversity. Moreover, single-voxel MR spectroscopy only shows the average of a large sample volume, which may include anaplastic and low-grade tumor portions as well as normal brain parenchyma. Therefore, lactate or lipid signals in small parts of the tumor may not be visible, and the maximum extent of the Cho increase and NAA loss will be underestimated. CSI is superior in spatial resolution, thus enabling the simultaneous characterization of smaller parts of the lesion, which is necessary for studying the lesion margins or defining targets for biopsy. Once the diagnosis of gliomatosis cerebri has been established, MR spectroscopy can also be used for follow-up examinations. The natural course is quite variable, with a duration between 25 days and 22 years (8, 42). Especially in low-grade lesions, radiotherapy is of questionable benefit and of potential harm (14, 43), even though some recent publications have reported a benefit from radiotherapy in patients with gliomatosis cerebri (6, 44). It has been shown that increased Cho/Cr and Cho/NAA levels and the appearance of lipids indicate malignant progression of a brain tumor (24). Thus, MR spectroscopy might be used to classify gliomatosis cerebri as a stable or a progressive disease with potential therapeutic relevance.

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