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MR Imaging: Possibility of Tissue Characterization of Brain Tumors Using T1 and T2 Values

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To evaluate the usefulness of T1 and T2 values for tissue characterization of brain tumors, 37 histologically confirmed brain tumors were examined with a 0.5-T superconductive MR system. With spin-echo and inversion-recovery imaging sequences, computed T1 and T2 images were reconstructed, and T1 and T2 values of the tumors were calculated. Relaxation rates (1/T1 and 1/T2), T1/T2 ratios, and malignancy indexes, which were originally designed for gastrointestinal tumors, were also calculated. Values of all these parameters were so wide-ranged that it was impossible to characterize the tumor tissue types.

Prolongation of the longitudinal relaxation times (T1) and the transverse relaxation times (T2) of protons in malignant tumors in vitro was first reported by Damadian [1] in 1971. Thereafter, many authors reported similar results [2–7], but some reported contrary findings [8, 9]. In the early 1980s, MR image quality improved markedly. Because of the high contrast between normal and abnormal tissues, MR imaging is a powerful diagnostic tool for detection of abnormal tissues. As a next step, MR imaging is expected to characterize abnormal tissues. In this report the usefulness of T1 and T2 parameters for tissue characterization of brain tumors in vivo is evaluated.

Subjects and Methods

Thirty-seven patients with histopathologically diagnosed brain tumor were examined with a cryogenic 0.5-T superconducutive MR system (Picker International, Cleveland) operating at 21 MHz, using a head coil with a diameter of 30 cm. Among the patients were 18 males and 19 females aged 9–79 years. Each patient was scanned with three consecutive pulse sequences: (1) a spin-echo (SE) sequence with a 2500 msec repetition time (TR) and 120 msec echo time (TE) (SE 2500/120); (2) SE 2500/40; and (3) an inversion-recovery (IR) sequence with TR 2500 msec, inversion time (TI) 600 msec, and TE 40 msec (IR 2500/600/40). A multiple-slice technique was used. Eight slices were imaged at once, and slice thickness was about 1.0 cm. One acquisition and a matrix of 256^2 were used. Images were reconstructed with 2DFT technique. Signal intensity of SE sequences is expressed as $(kp)\exp(-TE/T2)^*[1 - \exp(-TR/T1)]$, where k is a machine parameter and p is proton density. Signal intensity of an IR sequence, in which signals are read out with the SE sequence, is expressed as $(kp)\exp(-TE/T2)^*[1 - 2^*\exp(-TI/T1) + \exp(-TR/T1)]$. Computed T1 images were reconstructed pixel by pixel from the images of SE 2500/40 and IR 2500/600/40. Computed T2 images were also reconstructed from the images of SE 2500/40 and SE 2500/120. Regions of interest (ROIs) were determined on the computed T1 and T2 images to measure the T1 and T2 values of the tumors. These ROIs were made as large as possible. As for the tumors that contained a cystic portion, only the solid portions of the tumors were evaluated in our series. With these T1 and T2 values of the tumors, relaxation rates (1/T1 and 1/T2) were calculated. Furthermore, T1/T2 ratios and malignancy indexes were also calculated. Malignancy index [10] is expressed as $(T1/T1^*) + (T2/T2^*)$, where $T1^*$ and $T2^*$ are normal relaxation times. In our series, T1 and T2 values of the white matter of the frontal lobe of normal volunteers were used as $T1^*$ and $T2^*$.

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To evaluate the normal values of the relaxation times of the brain, 12 volunteers (five men and seven women aged 20–41) were examined in the same manner as described above. To evaluate the reproducibility of the relaxation times of our MR scanner from day to day, the T1 and T2 of a 1.0% $CuSO_4$ solution were examined in the same manner on 6 consecutive days.

Results

Histopathologic diagnoses, T1 and T2 values, relaxation rates (1/T1 and 1/T2), T1/T2 ratios, and malignancy indexes are presented in Table 1. In most cases relaxation times were prolonged. No characteristic features were found in the relaxation times of any tumor except meningioma. Meningiomas had relatively shorter T1 and T2 values than the other tumors. Some benign tumors had higher values of malignancy indexes than did malignant tumors, such as glioblastoma multiforme. T1 and T2 values of several parts of the normal brain are presented in Table 2. Reproducibility of the relaxation times of 1.0% $CuSO_4$ solution from day to day are shown in Table 3.

Representative cases are illustrated. A glioblastoma multiforme in a 54-year-old woman with motor aphasia (case 2) had moderately prolonged relaxation times (T1 and T2 were 901 and 109 msec, respectively) (Fig. 1). A follicle-stimulating-

TABLE 1: **Histopathologic Diagnoses, Age, Gender, Relaxation Times, Relaxation Rates, T1/T2 Ratios, and Malignancy Indexes**

Case No.	Age	Gender	msec (SD)		1/sec		T1/T2	Malignancy Index
			T1	T2	1/T1	1/T2		
Pilocytic astrocytoma:								
1	25	F	931 (45.4)	247 (43.5)	1.07	4.05	3.77	5.53
Glioblastoma multiforme:								
2	54	F	901 (62.8)	109 (5.6)	1.11	9.17	8.27	3.59
3	21	M	515 (62.8)	89 (17.8)	1.94	11.2	5.79	2.41
4	18	M	1256 (62.4)	170 (17.5)	0.796	5.88	7.39	5.24
5	30	M	825 (40.3)	95 (5.5)	1.21	10.5	8.68	3.21
Meningioma:								
6	42	M	678 (18.5)	106 (7.1)	1.48	9.43	6.40	3.02
7	53	M	959 (43.6)	72 (3.6)	1.04	13.9	13.3	3.22
8	49	F	774 (36.9)	75 (9.1)	1.29	13.3	10.3	2.83
9	43	M	737 (50.3)	63 (6.0)	1.36	15.9	11.7	2.58
10	68	F	716 (19.4)	67 (3.4)	1.40	14.9	10.7	2.58
11	64	M	783 (38.1)	80 (6.5)	1.28	12.5	9.79	2.92
12	69	F	738 (36.7)	64 (7.9)	1.36	15.6	11.5	2.59
13	73	F	912 (51.3)	83 (6.5)	1.10	12.0	11.0	3.26
14	38	M	760 (45.8)	94 (11.3)	1.32	10.6	8.09	3.05
15	67	F	1055 (46.0)	99 (8.0)	0.948	10.1	10.7	3.81
16	49	F	761 (24.8)	68 (3.5)	1.31	14.7	11.2	2.70
17	53	F	798 (50.9)	68 (9.4)	1.25	14.7	11.7	2.79
Pituitary adenoma:								
18	46	M	899 (59.7)	121 (7.4)	1.11	8.26	7.43	3.74
19	19	M	831 (40.1)	102 (9.1)	1.20	9.80	8.15	3.33
20	53	M	758 (47.8)	94 (10.5)	1.32	10.6	8.06	3.05
21	37	F	806 (54.6)	119 (22.6)	1.24	8.40	6.77	3.50
22	43	F	942 (49.1)	74 (11.7)	1.06	13.5	12.7	3.21
Neurinoma:								
23	31	F	887 (41.0)	92 (9.3)	1.13	10.9	9.64	3.32
24	40	F	1204 (147)	105 (21.1)	0.831	9.52	11.5	4.24
25	34	F	1160 (54.5)	106 (9.1)	0.862	9.43	10.9	4.15
26	79	M	1242 (85.7)	145 (18.0)	0.805	6.90	8.57	4.87
27	56	F	1316 (164)	114 (17.8)	0.760	8.77	11.5	4.62
28	51	M	966 (184)	140 (59.3)	1.04	7.14	6.90	4.16
Cavernoma:								
29	26	M	1030 (143)	76 (17.2)	0.971	13.2	13.6	3.44
30	32	F	894 (94.7)	104 (15.4)	1.12	9.62	8.60	3.50
Chordoma:								
31	22	F	846 (103)	111 (24.9)	1.18	9.01	7.62	3.48
Teratoma:								
32	9	M	1515 (108)	125 (15.0)	0.660	8.00	12.1	5.24
Craniopharyngioma:								
33	41	M	733 (34.1)	111 (14.5)	1.36	9.01	6.60	3.22
Malignant lymphoma:								
34	65	F	1051 (94.0)	83 (12.8)	0.951	12.0	12.7	3.58
Metastasis (adenocarcinoma):								
35	30	F	782 (34.6)	63 (5.9)	1.28	15.9	12.4	2.68
36	73	M	784 (109)	105 (21.4)	1.28	9.52	7.47	3.26
37	59	M	926 (74.0)	75 (18.1)	1.08	13.3	12.3	3.18

hormone–producing pituitary adenoma in a 19-year-old man with gradually decreasing visual acuity for 5 years (case 19) also had moderately prolonged relaxation times (T1 and T2 were 831 and 102 msec, respectively) (Fig. 2). A trigeminal neurinoma in a 34-year-old woman with oculomotor palsy and hypalgesia in the territories of the first and second divisions of the right trigeminal nerve (case 25) had prolonged T1 (1160 msec) and moderately prolonged T2 (106 msec) (Fig. 3).

TABLE 2: **Normal T1 and T2 Values at 0.5 T**

Tissue	T1 in msec (SD)	T2 in msec (SD)
White matter:		
Frontal lobe	428.4 (48.0)	73.5 (4.9)
Occipital lobe	472.8 (45.5)	74.5 (4.3)
Internal capsule	478.2 (72.9)	75.4 (4.9)
Gray matter:		
Caudate head	648.9 (75.6)	88.3 (6.5)
Lenticular nucleus	592.5 (72.2)	82.5 (7.3)
Thalamus	568.4 (58.6)	78.8 (5.5)
Brainstem:		
Pons	689.0 (21.7)	79.8 (7.0)
Cerebellum:		
Peduncle	652.0 (38.4)	89.9 (9.8)
Hemisphere	836.5 (46.7)	85.7 (5.8)
Retroorbital fat	380.3 (45.3)	64.2 (5.0)

Discussion

Prolongation of the proton relaxation times of malignant tumors (Walker sarcoma and Novikoff hepatoma) was reported by Damadian [1] and confirmed by others [2–7]. Relaxation times are fairly good parameters for differentiation

TABLE 3: **Reproducibility of T1 and T2 of 1.0% $CuSo_4$ Solution**

Day	T1 (msec)	T2 (msec)
1	234	146
2	235	141
3	236	142
4	231	148
5	227	145
6	233	146

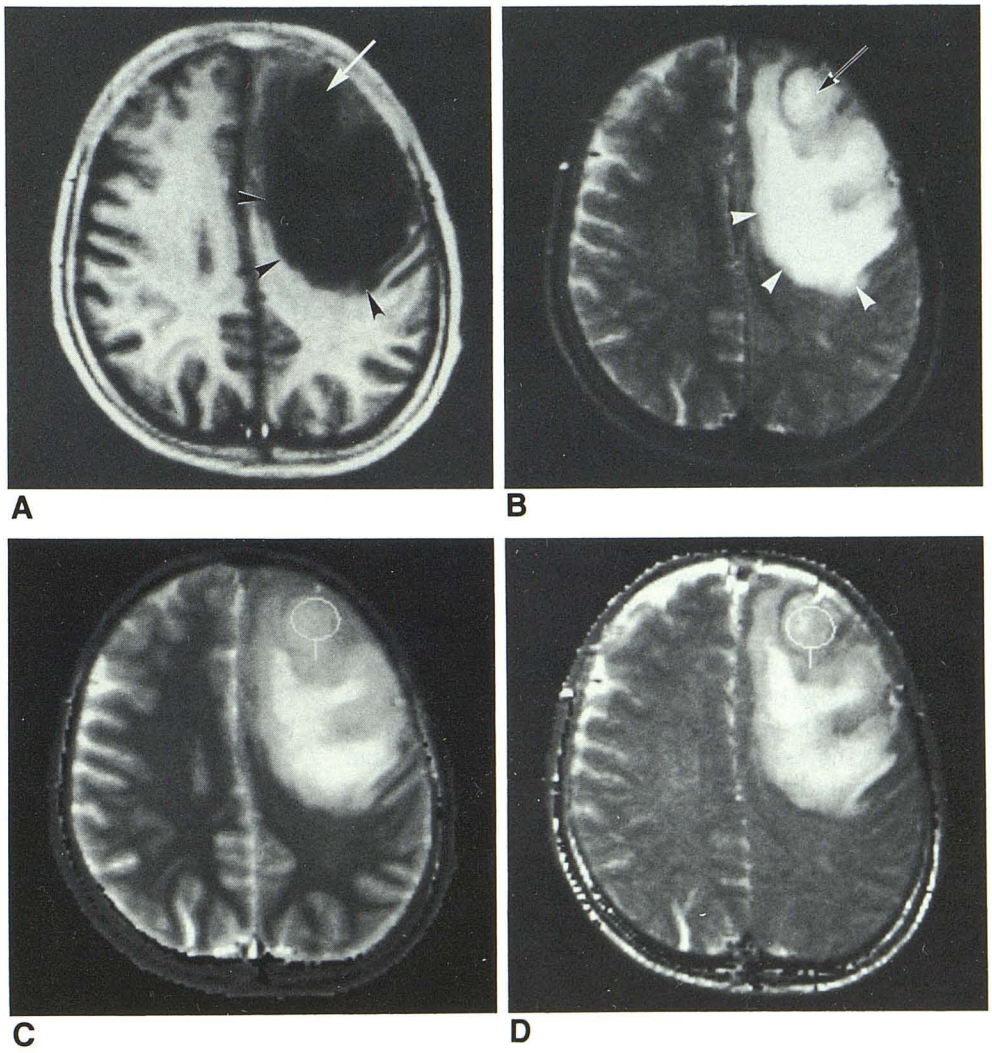

Fig. 1.—Case 2. Glioblastoma multiforme in 54-year-old woman.

***A*, IR 2500/600/40. Tumor (*arrow*) shows slightly lower intensity than gray matter. Surrounding edema (*arrowheads*) shows much lower intensity than tumor.**

***B*, SE 2500/120. Tumor (*arrow*) shows higher intensity than gray matter and edema (*arrowheads*) shows much higher intensity than tumor.**

***C*, Computed T1 image reconstructed from IR 2500/600/40 and SE 2500/40 images. ROI is in circle. T1 of ROI is 901 msec.**

***D*, Computed T2 image is reconstructed from SE 2500/120 and SE 2500/40 images. T2 of ROI is 109 msec.**

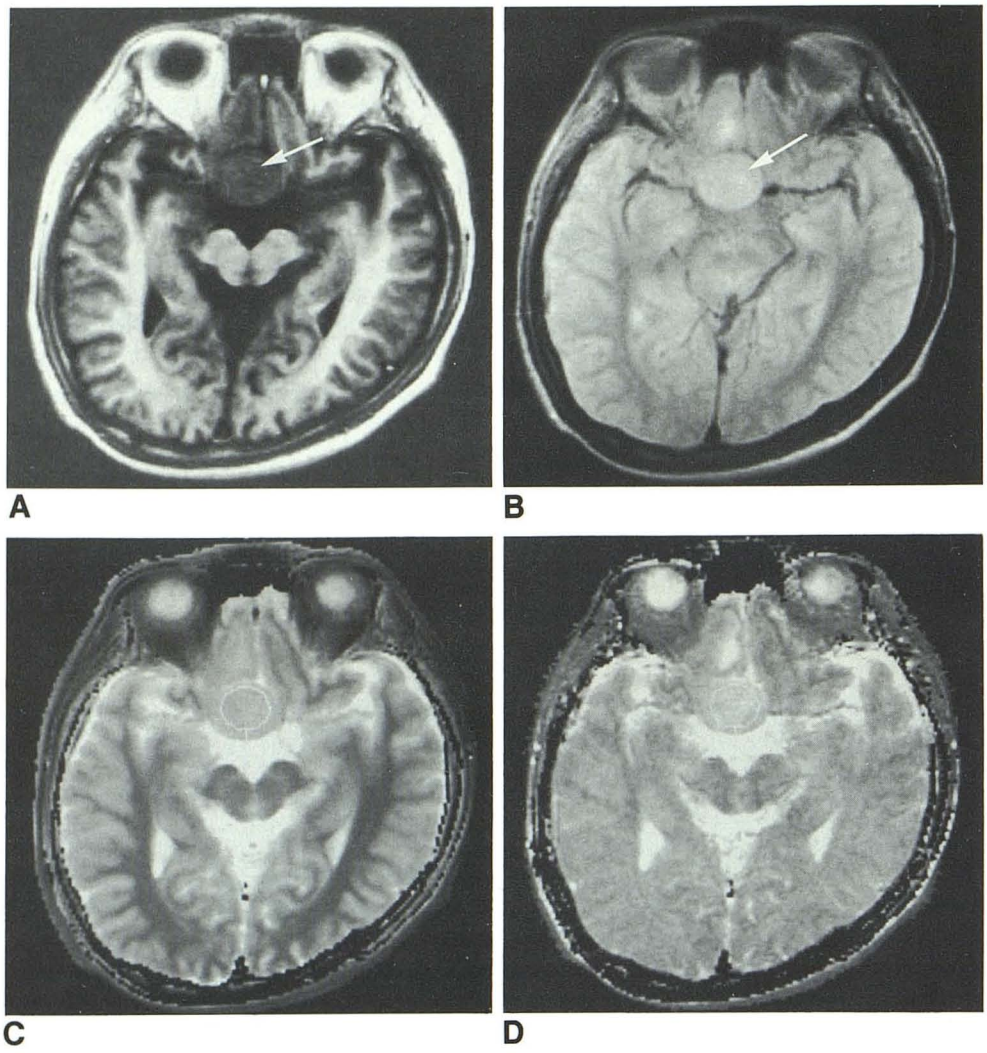

Fig. 2.—Case 19. Follicle-stimulating-hormone–producing pituitary adenoma in 19-year-old man.

***A*, IR 2500/600/40. Tumor (*arrow*) shows slightly lower intensity than gray matter.**

***B*, SE 2500/40. Tumor (*arrow*) shows higher intensity than gray matter.**

***C*, Computed T1 image reconstructed from IR 2500/600/40 and SE 2500/40 images. ROI is in circle. Its T1 is 831 msec.**

***D*, Computed T2 image reconstructed from SE 2500/120 and SE 2500/40 images. T2 of ROI is 102 msec.**

between normal and abnormal tissues. However, this appeared not to be applicable to the central nervous system because the distribution of relaxation times of normal brain overlaps considerably with that of brain tumors [8]. Using these relaxation times, the possibility of characterizing brain-tumor tissue is of much interest, but at present is controversial.

Araki et al. [11] reported that it was difficult to predict histologic types of brain tumors by measuring T1 alone because of the wide variation in relaxation times. The same results were shown by Brady et al. [12], who concluded that the specificity of lesion characterization using T1 data was low because of the wide range of the T1 data. Eggleston et al. [9] also reported that the T1s of abnormal nonneoplastic tissues were longer, in many instances, than those of malignant tumors from similar sites, preventing recognition of the tumors in this manner. They were pessimistic about characterizing tissue using T1 values. Similarly, Rinck et al. [13] reported that T2 values did not allow discrimination among tumors, nor did they allow differentiation between tumor, inflammatory tissue, and demyelination.

There has been no report so far on a clinical evaluation of a wide variety of the brain tumors using both T1 and T2 values. As described in our report, we obtained both T1 and T2 values in 37 brain tumors. Although in almost all the cases relaxation times were prolonged relative to those in normal volunteers, it was difficult to differentiate benign from malignant tumors. Meningiomas had relatively shorter T1 and T2 values (averages were 806 and 78.3 msec, respectively) than the other tumors (averages were 960 and 111 msec, respectively). T1 and T2 values of meningiomas are significantly shorter than those of the other tumors ($p < 0.05$ and $p < 0.01$, respectively). However, this does not mean that a tumor that has shorter relaxation times is a meningioma. At present, we believe that even with both T1 and T2 values, a specific diagnosis of malignancy on the basis of relaxation values alone cannot be made because of a significant overlap of the T1 and T2 of benign and malignant tissues [14–16].

Prolongation of the relaxation times is thought to correlate with the tissue-water content [5, 17–19]. Neoplasms have

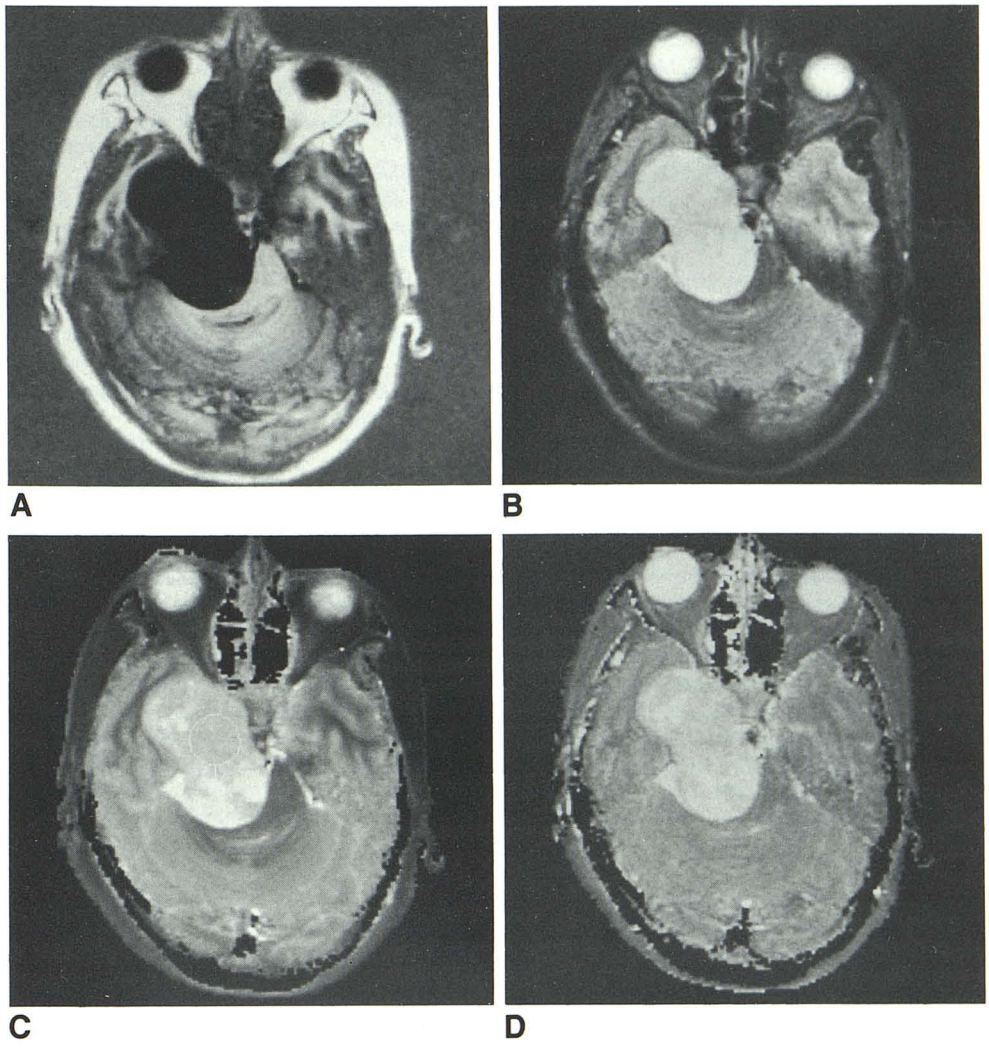

Fig. 3.—Case 25. Trigeminal neurinoma in 34-year-old woman.

***A*, IR 2500/600/40. Tumor shows markedly low intensity.**

***B*, SE 2500/120. Tumor shows higher intensity than brain tissue.**

***C*, Computed T1 image is reconstructed with images of IR 2500/600/40 and SE 2500/40. ROI is in circle. Its T1 is 1160 msec.**

***D*, Computed T2 image reconstructed from SE 2500/120 and SE 2500/40 images. T2 of ROI is 106 msec.**

longer relaxation times due to the greater hydration, and T1 is more sensitive than T2. Kiricuta and Simplăceanu [19] concluded that MR relaxation techniques appear to be much less promising for the detection of cancerous tissues than was originally thought. Tissue relaxation rates (1/T1 and 1/T2) are mainly dependent on total water content [14]. Relaxation rates in our series had such wide ranges that there were no characteristic features.

Medina et al. [20] showed the usefulness of the T1/T2 ratio for the differentiation of malignant from nonmalignant tissue in a study on breast cancer. In our series, the T1/T2 ratio was applied to brain tumors. Contrary to their results, there was no significant difference between malignant and nonmalignant brain tumors.

The malignancy index was first introduced in a study of human gastrointestinal tumors by Goldsmith et al. [10]. They stated that this malignancy index allowed complete discrimination between normal tissue and malignant tumor. In our series, the malignancy index was applied to brain tumors. For the values of normal tissue, we used T1 and T2 of frontal white matter. The malignancy index did not discriminate glioblastoma multiforme from benign brain tumors. Even some benign brain tumors had high values on the malignancy index. High values on the malignancy index did not always correspond to the malignancy of the tumors. Although the number of cases in our series was small, the malignancy index did not appear useful for brain tumors.

In conclusion, T1 and T2 were prolonged in almost all brain-tumor cases, but it was difficult to differentiate the tumor types on the basis of relaxation times alone. T1/T2 ratios and malignancy indexes were also not helpful in differentiating malignant brain tumors. These results were discouraging for clinical use in tissue characterization. However, further work is required before final conclusions are reached.

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