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Paradoxically Decreased Signal Intensity on Postcontrast Short-TR MR Images

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Seven lesions are presented in which short TR/short TE images obtained immediately after IV administration of gadopentetate dimeglumine demonstrated an apparent decrease in signal intensity compared with precontrast short TR/short TE images. All seven lesions were hyperintense on precontrast short TR/short TE images. In four cases in which long TR/long TE scans were also obtained, the lesions were hypointense.

This phenomenon may be due to a dominant T2 shortening effect by the contrast material that "overwhelms" T1 shortening even on short TR/short TE scans. Other compounding factors may include variations in scanning variables, receive and transmit attenuations, or a photographic phenomenon due to window widths and center levels.

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The use of gadopentetate dimeglumine for evaluating CNS disease has become commonplace. With a standard dose of 0.1 mmol/kg, lesions that show contrast enhancement usually become bright on short TR/TE images. The explanation for this phenomenon is the shortening of T1 relaxation by the paramagnetic contrast agent on adjacent protons. As with any dipolar interaction, T2* shortening also occurs; however, its effect is usually inapparent on the short TR/short TE (T1-weighted) scans. We present seven cases in which there was a decrease in signal intensity after IV administration of contrast material in lesions that were hyperintense on precontrast short TR/short TE scans.

Materials and Methods

In the past 2 years we have observed seven cases in which there appeared to be a *decrease* in lesion signal intensity on postcontrast short TR (600–850)/short TE (20/30) images compared with precontrast scans. All scans were obtained on high-field 1.5-T scanners. Standard doses of gadopentetate dimeglumine (Magnevist, Berlex Industries, Wayne, NJ) at 0.1 mmol/kg were administered intravenously followed by immediate (i.e., < 5 min) postcontrast short TR scans.

In three cases (Figs. 1–3) the absolute lesion signal intensities and the lesion/CSF, lesion/gray matter, and lesion/white matter intensity ratios were determined on short TR/short TE scans obtained before and after contrast administration using a region of interest (ROI) with a size of 0.5 cm^2. The ratios were used to provide an internal control, since it is expected that stationary CSF, gray matter, and white matter will not show significant contrast enhancement. The subarachnoid space about the vertex of the brain, the caudate nucleus head, and the genu of the corpus callosum were used for the CSF, gray matter, and white matter measurements, respectively. The matrix size in these scans was 256 × 192 with 3-mm-thick sections and one excitation. ROIs were taken in the exact same location in the lesion by not moving the ROI or changing its size while going from pre- to postcontrast series. Background noise was subtracted from all measurements by sampling a similar-sized ROI outside the patient's body. The TRs, TEs, matrices, slice thicknesses, and number of excitations were identical before and after contrast administration in all three cases, and in one case (Fig. 2) the receive and transmit attenuations were also identical.

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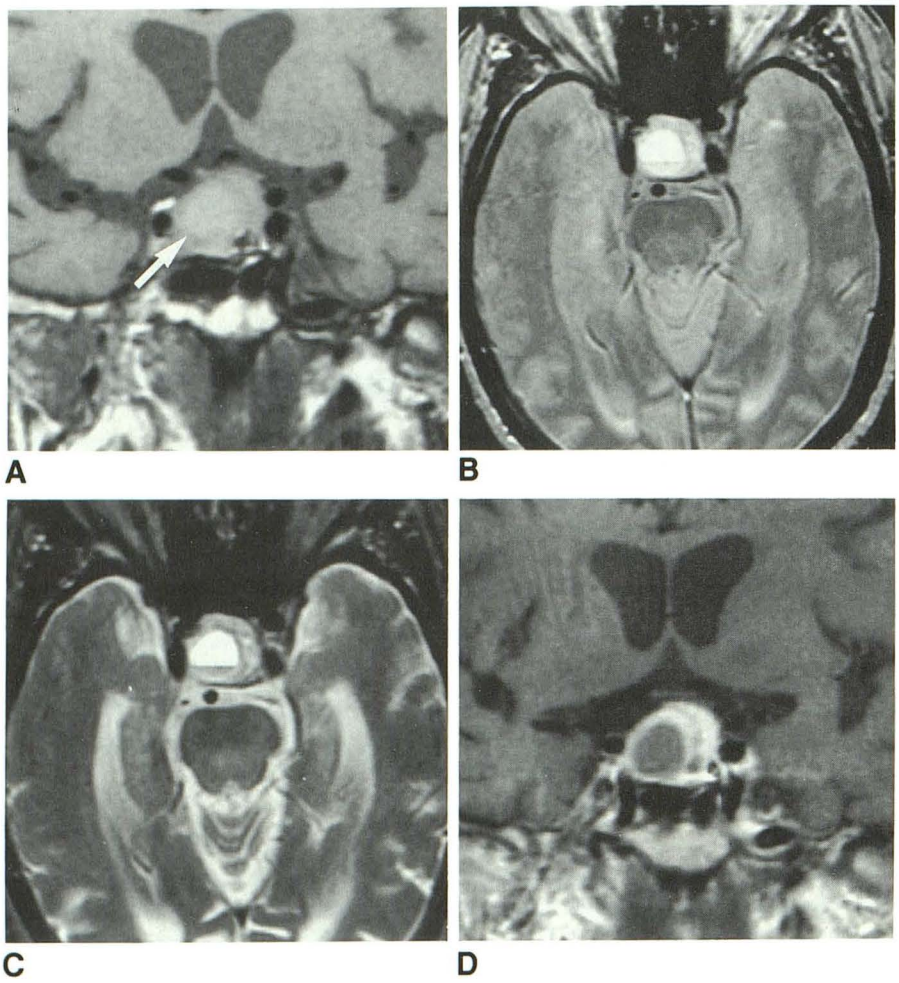

Fig. 1.—Hemorrhagic pituitary adenoma with reversal of intensity pattern after contrast enhancement in 79-year-old man with bitemporal hemianopsia.

***A*, Precontrast coronal MR image (800/25) shows a 2-cm pituitary mass with focal area of higher signal on right side of tumor (*arrow*). Optic chiasm is compressed upward.**

***B*, Precontrast MR image (3000/35) shows a fluid level within mass, presumably from various states of intratumoral hemorrhage with mixing.**

***C*, Precontrast long TE (3000/90) MR image shows a decrease in intensity of posteriorly layering collection, signifying a short T2 effect. Figs. 1A and 1D are sectioned through this portion of mass.**

***D*, Precontrast MR image (800/25) shows decrease in signal intensity in area where precontrast image had demonstrated higher intensity. The rest of the adenoma enhances dramatically. Window widths and centers were identical in Figs. 1A and 1D. Receive and transmit attenuation variation may account for background intensity variation.**

Experimental Model

To better understand the effect of contrast material on signal intensity and T1 and T2 relaxation values, serial 5-ml dilutions of gadopentetate dimeglumine (0.5 mmol/kg) were placed in test tubes ranging from 0.06 mmol/kg to 0.000063 mmol/kg of the contrast material in normal saline. These tubes were then scanned by using the MR parameters employed at our institution for routine sellar masses (800/25/2). Without intervening prescanning, a four-echo (2500/25,50,75,100/1) scan was also obtained to determine T1 and T2 values.

Results

We found seven patients with lesions that demonstrated an apparent decrease in signal intensity on postcontrast MR images. Three patients had pathologically proved pituitary adenomas (Figs. 1 and 4). A fourth case was presumed to be a prolactinoma on the basis of serum prolactin levels, although no histologic proof had been obtained. There was one pathologically proved craniopharyngioma (Fig. 2). One patient refused surgery; however, his lesion was thought to be either a craniopharyngioma or a Rathke cleft cyst (Fig. 3). One patient had widely metastatic melanoma with cervical lymphadenopathy (Fig. 5).

In five cases, the pre- and postcontrast images were obtained with the same TR/TE/number of excitations (800/20–26/1). In one case the postcontrast scan employed a shorter TR (600) than the precontrast image (800). In another case the postcontrast TR/TE was extended to 1100/30 from precontrast values of 600/20. In one case the receive and transmit gains were known to be identical (Fig. 2). In the other cases where the TR and TE were identical, minor variations in receive and transmit gain levels may have occurred but were not documented. Long TR/long TE scans were obtained in four patients, and the signal intensity of at least part of the masses was iso- to hypointense relative to gray matter in all cases.

In the three cases in which ROIs through the lesions were measured (Figs. 1–3), there was an absolute decrease in the signal intensity of the lesions by 29%, 17%, and 5.3%, respectively, after contrast enhancement. In each case there was also a decrease in the lesion/CSF, lesion/gray matter, and lesion/white matter ratio (Table 1). The percentage decrease in intensity after contrast administration in the three cases measured by the quotient of [(precontrast ratio)–

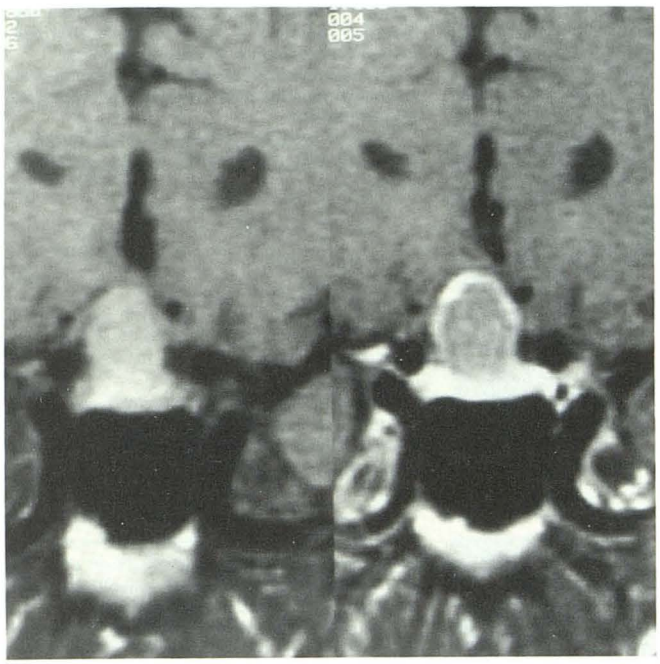

Fig. 2.—Hemorrhagic craniopharyngioma with decrease in apparent intensity on postcontrast images in a 66-year-old man with acute headaches.

Left and *right*, Pre- (*left*) and immediate postcontrast (*right*) MR images (800/25) show a decrease in intensity of hemorrhagic 2-cm craniopharyngioma on postcontrast image. Tumor/CSF ratio fell from 3.21 to 2.91, tumor/gray matter ratio fell from 1.39 to 1.28, and tumor/white matter ratio fell from 1.25 to 1.13 with TR, TE, and receive and transmit attenuation kept constant. The same window widths and centers were used.

(postcontrast ratio)]/(precontrast ratio) ranged from 5.2–9.8% for the lesion/CSF ratio. The range for the lesion/gray matter decrease in intensity after contrast administration was 5.0–7.9%, and for lesion/white matter it was 5.3–9.7%. Although in cases 1 and 2 the TR and TE were identical before and after contrast administration, in case 3 the precontrast TR was 800 and the postcontrast TR was 600.

The absolute values of the CSF in the three cases above demonstrated reduction in CSF signal in two cases by 0.5% to 2.8% and elevation of the CSF signal in one case by 5%. These minor fluctuations may represent effects of variations in receive and transmit attenuations, CSF flow effects, or the effect of contrast material on these factors.

In case 2, a four-echo pulse sequence was used with a TR of 2500 and TEs of 20, 40, 60, and 80. A short TR scan (800/20) was also obtained before and after contrast administration and without intervening changes in the receive and transmit gains. From this data set, the T2 values before and after contrast administration were calculated. The precontrast T2 value was calculated to 87 ± 4 msec (SD) and the postcontrast value was 68 ± 3 msec.

Experimental Model

A graph depicting contrast material concentration versus signal intensity (with background noise subtracted) is presented in Figure 6. It can be seen that at concentrations higher than 0.001 mmol/kg and lower than 0.0005 mmol/kg the signal intensity of the contrast solution decreases. The

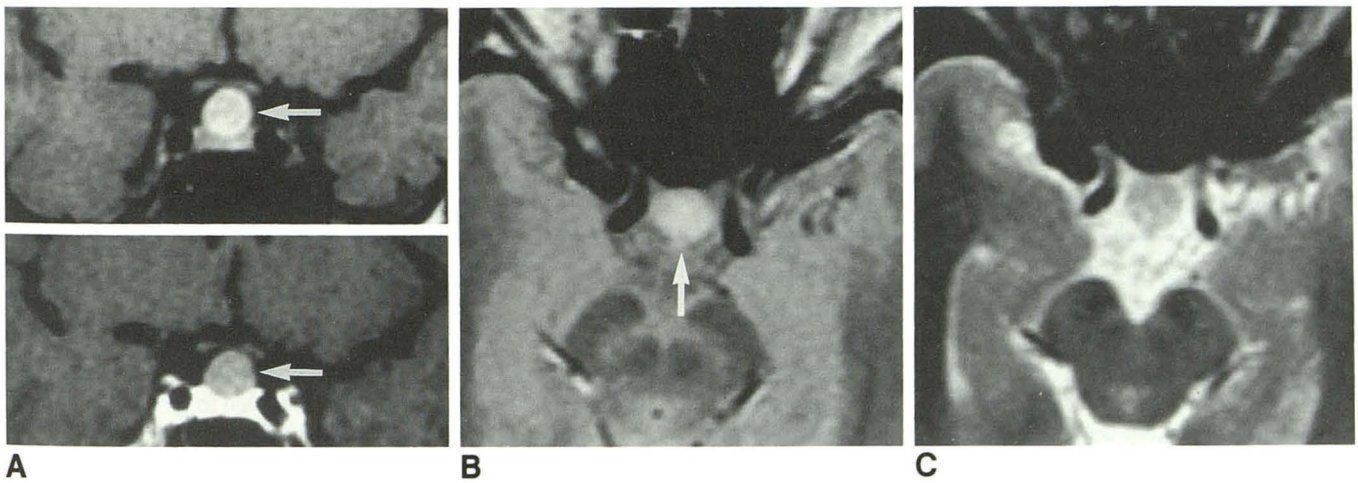

Fig. 3.—Suprasellar craniopharyngioma or Rathke cleft cyst in 31-year-old man with facial numbness that showed paradoxical decrease in intensity after contrast administration.

A, Precontrast (800/20/1) (*top*) and postcontrast (600/20/1) (*bottom*) MR images show apparent decrease in signal intensity of the 1-cm suprasellar mass (*arrow*) after contrast administration. Note that signal intensity of gray and white matter is different between the two scans owing to the different TR values and receive and transmit attenuation values on the prescan. Window widths and centers are set at identical values. The lesion was high in density on an unenhanced CT scan.

B, MR image (3000/30) shows high-intensity mass (*arrow*) between the cavernous carotid artery flow voids.

C, On second-echo image (3000/90), signal intensity has decreased so that lesion is now isointense with cortex. Its T2 relaxation value is unlikely to be very prolonged.

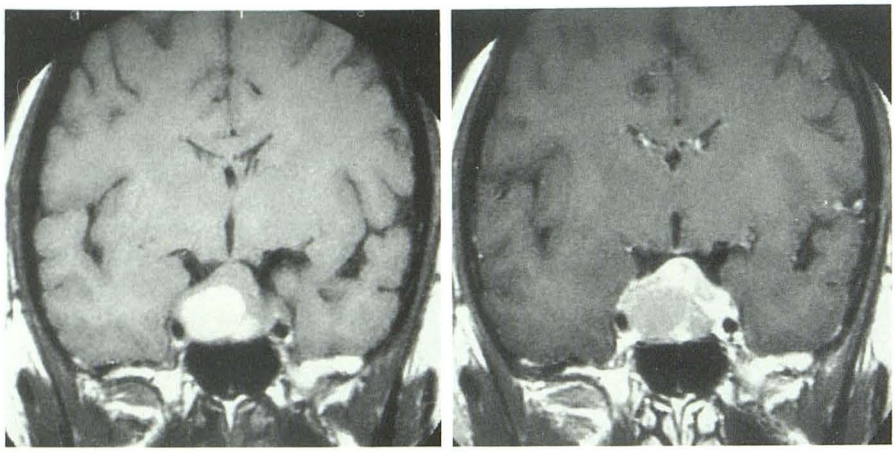

Fig. 4.—Hemorrhagic pituitary adenoma with apparent decrease in signal intensity after contrast enhancement in 42-year-old woman.

A, Large hemorrhagic pituitary adenoma demonstrates high signal intensity on precontrast MR image (600/20).

B, After contrast enhancement, an apparent decrease in signal intensity occurs on 600/20 scan.

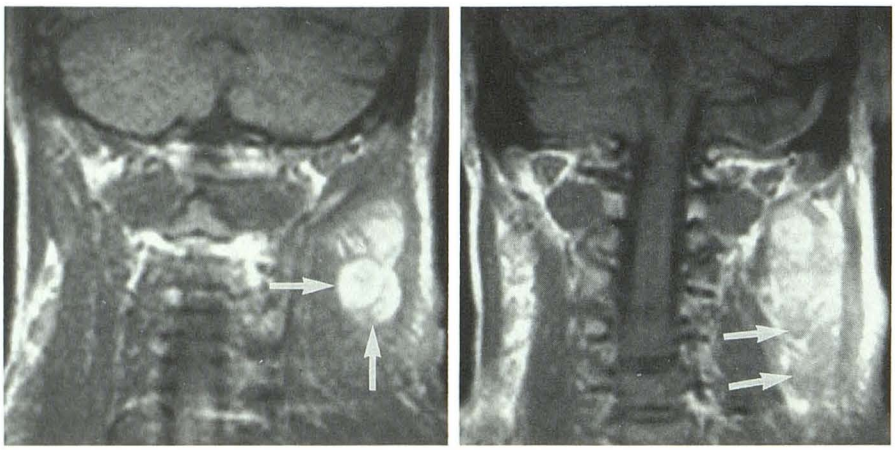

Fig. 5.—Metastatic melanoma nodes with apparent decrease in signal intensity on postcontrast coronal images in a 36-year-old man with pathologically proved melanoma.

A, Precontrast coronal MR image (800/20) of the neck of a patient with metastatic melanoma nodal disease shows high signal intensity lymphadenopathy on left side (*arrows*).

B, Postcontrast image (800/20) with same window width and level settings shows decrease in signal intensity in lower nodal group (*arrows*). Identical window widths and levels were used.

TABLE 1: Comparison of Lesion/CSF, Lesion/Gray Matter, and Lesion/White Matter Ratios Before and After Contrast Administration

Case No.	Precontrast Lesion/CSF Ratios	Postcontrast Lesion/CSF Ratios	Precontrast Lesion/Gray Matter Ratios	Postcontrast Lesion/Gray Matter Ratios	Precontrast Lesion/White Matter Ratios	Postcontrast Lesion/White Matter Ratios
1[a]	2.15	1.94	1.19	1.13	1.13	1.02
2[a]	3.21	2.91	1.39	1.28	1.25	1.13
3[b]	2.51	2.38	1.32	1.23	1.33	1.26

[a] Pre- and postcontrast values were 800/25 (TR/TE).
[b] Precontrast values were 800/20 (TR/TE), postcontrast values were 600/20 (TR/TE).

effect at higher concentrations is due to extreme T1 and T2 shortening, whereas at the lower concentration, a decrease in proton relaxation enhancement occurs with very dilute contrast solution.

Graphs of contrast material concentration (Figs. 7 and 8) and signal intensity (Figs. 9 and 10) versus calculated T1 and T2 values derived from the data set with varying concentrations of contrast material show that although T1 and T2 values fall with increasing contrast concentration, signal intensity does decrease even at very low T1 values owing to the concurrent T2 shortening effect. One will note that as the calculated T2 value decreases from 87 to 68, as in the clinical data derived from case 2, the signal intensity does show a decline. However, it must be stressed that this requires applying T2 values of a lesion in the brain to graphs developed by using test tube data. Additionally, the TE values of the sequence used for calculation of the T2 of the lesion were 20, 40, 60, and 80, whereas those for the test tubes were 25, 50, 75, and 100. The effect of varying TEs should be negligible, but must be borne in mind when interpreting these graphs.

Discussion

The seven unpaired electrons of gadolinium produce a net magnetic moment that induces proton relaxation enhance-

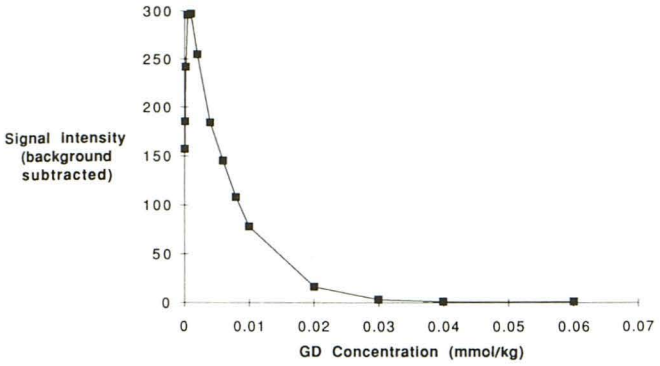

Fig. 6.—Graph depicting signal intensity vs contrast concentration. The signal intensity of serial dilutions of contrast material increases initially with dilution. Intensity then decreases with further dilution. Scans were obtained at 800/25 on a 1.5-T unit.

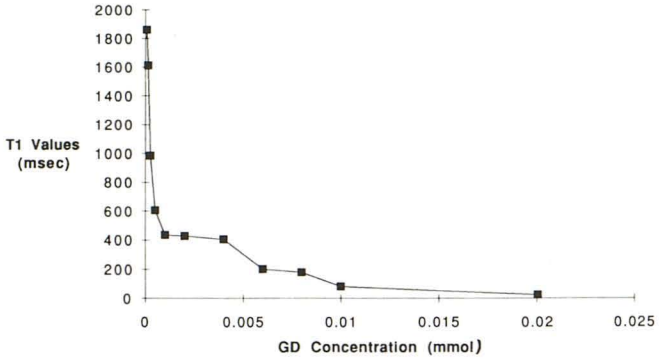

Fig. 7.—Graph depicting calculated T1 values vs contrast concentration. As concentration of contrast material increases, calculated T1 values based on 800/25 and 2500/25,50,75,100 data also decrease. This would be expected to cause high signal intensity on short TR/TE scans (800/25 was used).

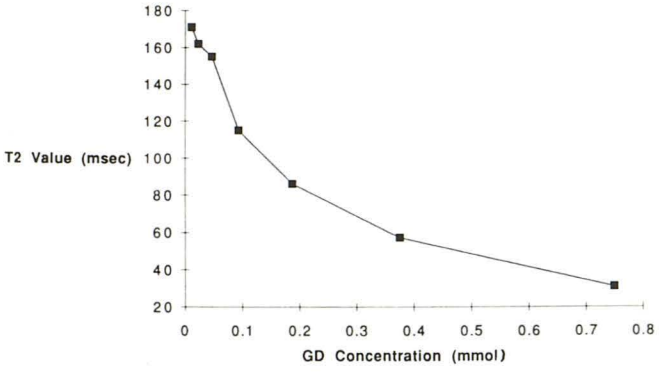

Fig. 8.—Graph depicting calculated T2 values vs contrast concentration. As concentration of contrast material increases, calculated T2 values based on 2500/25,50,75,100 data decrease. This factor would be expected to cause decrease in signal intensity, counteracting the T1 effect.

ment or shortening of the T1 and T2 relaxation times of neighboring protons [1–5]. The predominant effect when employing short TR/TE scans after contrast injection is that of T1 shortening, which causes the increased signal intensity. It has been recognized, however, that the T2 shortening effect

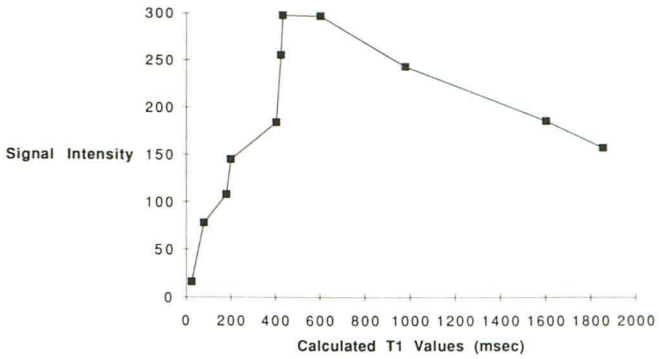

Fig. 9.—Graph of signal intensity observed in the contrast phantom with the 800/25 sequence and calculated T1 values shows the paradoxical decrease in signal intensity at lower T1 values. This is occurring at T1 values below 450 msec. One would normally expect a shorter T1 to cause higher, not lower, intensity. The reason for this paradoxical decrease in intensity is that the contrast is also shortening T2 relaxation. The T2 shortening effect becomes preeminent at this concentration of contrast material, even on a T1-weighted (800/25) scan.

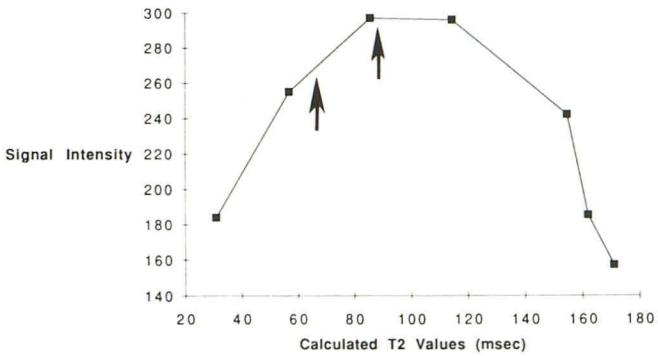

Fig. 10.—Graph of signal intensity from an 800/25 scan versus T2 values from 2500/25,50,75,100 data shows the peak in signal intensity occurring at the point where the T2 value is 86 msec. At T2 values below this level, the signal intensity falls despite the fact that the T1 values are still decreasing (Fig. 9). *Arrows* mark the T2 values (87 and 68 msec) derived from the calculations performed on craniopharyngioma study (case 2) with 2500/20,40,60,80 data. Note that at this side of the curve, the signal intensity is decreasing, since the T2 shortening effect is preeminent here. The extrapolation of in vivo data to this in vitro test tube graph must be viewed with some reservation, particularly since the TE values were not the same. Nonetheless, the potential of this explanation to apply to the observed paradoxical phenomenon can be demonstrated by the graphs.

also occurring in dipole-dipole interactions can affect signal intensity. For example, concentrated contrast material in the bladder and kidney may show low intensity as it accumulates owing to the effect of a markedly shortened T2 becoming dominant even in short TE scans [6, 7]. Thus, the opposing influences of T1 shortening causing increased signal intensity and T2 shortening causing decreased signal intensity conflict when high concentrations of contrast material are present. Figures 9 and 10 demonstrate that one can have a situation in which T1 values are decreasing on a T1-weighted scan yet the signal intensity will fall if a concomitant T2 reduction is preeminent.

We have observed an apparent decrease in signal intensity after contrast enhancement in seven lesions over the past 2 years. One explanation of the observed phenomenon is that

the lesions had such short T2 values to begin with (as evidenced by their low signal intensity on the long TR/long TE scans) that the added T2 shortening effect of the contrast agent placed the lesion on the downslope of the intensity curve, overwhelming the T1 shortening effect (see Figs. 6, 9, and 10). This hypothesis is supported by the high density on CT of the lesion in case 3, which may be due to calcification and/or hemorrhage, both of which may be associated with paramagnetism. At least three patients had hemorrhage, which was documented at pathologic examination. The same phenomenon can be attributed to the melanin in the metastatic lymph nodes in case 5. The data presented in the experimental model section supports the notion that the T2 effect can explain the observed phenomenon, particularly in case 2, in which the T2 values fall on the steep slope of signal intensity decline in Figure 10. However, extrapolation of the test tube data to in vivo settings must be viewed with some wariness. Doubt still remains.

While this is an attractive hypothesis (but not conclusively proved in this study), other factors may affect the observed intensity in the cases provided. Variations in TR, TE, and receive and transmit attenuation may alter intensity values. This may account for the higher intensity on the more T2-weighted postcontrast scan, in which the TR and TE were extended to 1100/30; however, the reduction in TR from 800 to 600 in one case on the postcontrast scan would be expected to provide more T1 contrast. We also believe that the minor variations in receive and transmit attenuation values when the TR and TE are kept constant are unlikely to cause the changes in signal intensity in the cases shown. In our experience these values vary only minimally between successive pre- and postcontrast scans. Additionally, these factors cannot explain the case in which TR, TE, and receive and transmit attenuation were all kept constant (case 2). Others may argue that the TRs and TEs used (TRs of 800 in five cases and 1100 in one case, and TEs of 26–30) are not truly T1-weighted and have sufficient T2-weighting to cause the contrast-induced T2 shortening to influence signal intensity.

Alternatively, the paradoxical decrease in intensity may be a perceptual artifact as one contrasts the very high intensity of the adjacent enhancing cavernous sinus and normal pituitary gland with the lesion. Variations in window widths and levels can accentuate the differences between pre- and postcontrast scans and contribute to the paradox of seeing an apparent decrease in intensity on postcontrast images. The absolute intensity values and ratios before and after contrast enhancement in our cases did not differ widely in the lesions, and we believe that this visual illusion may play a role in our *perception* that the intensity fell between scans. This would explain the preponderance of cases that occur in the sellar region (i.e., the bright contrast of the cavernous sinus). However, this explanation does not address the findings that the relative intensity measurements of the lesion/CSF, lesion/gray matter, and lesion/white matter ratios also decreased on the postcontrast study in the three cases in which this was measured.

Another explanation for the preponderance of cases about the sella is that lesions here do not have to cross the blood-brain barrier. Direct arterial supply to the lesions from internal carotid branches cause maximum enhancement to occur at 60–90 sec, according to Sakamoto et al. [8]. This rapid, intense delivery of contrast material to the area coupled with the additive effects of hemorrhagic tumorous tissue could dramatically influence signal intensity in the sellar lesions by combining magnetic inhomogeneities of blood products and contrast agent. The hypervascular metastases of melanoma could account for a similar high rate of contrast infusion into the metastatic melanoma lymph nodes.

The lesions presented are all lesions that show contrast enhancement typically. The argument that hematomas in tumors should not enhance can be addressed by observing the lesions histologically. The pathologic findings were not those of pure clots, but hemorrhagic tumor—tumor admixed with blood. Thus, there would be enhancement and contrast delivery to these lesions.

Whether the paradoxical drop in signal intensity has a basis in paramagnetism and T1 and T2 shortening effects or is merely a manifestation of scan technique variability, photographic manipulation, and visual perception, the curious observation that apparent signal intensity in lesions can fall after contrast administration exists. "Enhancement" may be occurring even though there is an apparent *decrease* in signal intensity on postcontrast T1-weighted scans. The issue is not entirely moot, since if the effect is totally a photographic one, then one would expect that it would be maximized when the lesion does *not* enhance but the surrounding tissues do. Additionally, this phenomenon emphasizes the need for precontrast short TR/short TE images, since hemorrhagic or melanin-containing lesions might escape detection on postcontrast scans only.

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The reader's attention is directed to the commentary on this article, which appears on the following pages.