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White Matter Buckling: CT Sign of Extraaxial Intracranial Mass

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The resolution of present day computed tomography (CT) scanners routinely permits discrimination of gray from white matter with delineation of a gray-white matter interface. Superficially situated extraaxial masses usually preserve the gray-white interface and tend to compress and/or buckle adjacent edematous white matter. This does not occur with superficially situated intraaxial lesions and is, therefore, essentially diagnostic of an extraaxial mass. It is postulated that this sign reflects the relative resistance of gray matter to edema in conjunction with the destruction of the gray-white interface by the infiltration of intraaxial lesions. White matter buckling is almost invariably associated with extracerebral fluid collections. It is less often discernible in association with meningioma. In a series of 100 consecutive proven meningioma cases, compression and/or buckling of central white matter was demonstrated in 28, and in 28 (40%) of 70 superficially situated lesions. White matter buckling is diagnostically significant when it occurs. It has been especially helpful in the diagnosis of otherwise atypical superficial masses.

The typical appearance on computed tomography (CT) of extraaxial intracranial masses, notably meningiomas [1, 2] and extracerebral hematomas [3–11], has been extensively reported. The specific effects on adjacent gray and white matter have not been adequately defined. Definition of these changes is now diagnostically important since the resolution of present day CT scanners routinely permits discrimination of gray from white matter with delineation of a gray-white matter interface [12, 13]. We found that compression and/or inward buckling of central white matter and the gray-white interface localizes a lesion to the extraaxial compartment. This sign, buckled white matter, has been especially helpful in the diagnosis of otherwise atypical superficially placed lesions such as meningioma and isodense subdural hematoma.

Normal CT Anatomy

In the normal cerebral hemisphere, white matter is depicted as an area of relative lucency surrounded by a zone of greater attenuation value representing gray matter [12, 13]. In transverse section, the configuration of white matter is roughly semilunar with a flat base medially paralleling the interhemispheric fissure and the medial cortex (figs. 1 and 2). The dome of central white matter is directed laterally with frondlike projections insinuated within the lateral cortical gray matter. Thus the shape of central white matter roughly resembles that of a porcupine; its contour parallels that of the cerebral hemisphere (figs. 1 and 2).

The difference in attenuation value between gray matter and white matter varies widely and is a function of several factors: (1) age of the patient (the separation is seen better in younger age groups) (George AE, Russell EJ, Kricheff II, unpublished data); (2) proximity to the vertex [14]; (3) presence or absence of edema; and (4) a variety of technical factors including the low contrast discriminatory ability of the particular scanner, scan time, and radiation dose. Gray
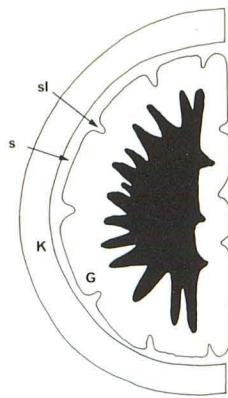
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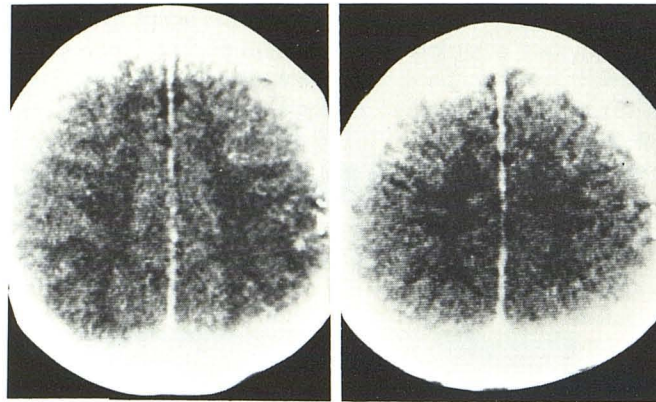
2A   **2B**

Fig. 1.—Normal transverse axial CT scan at centrum semiovale above lateral ventricles. Fronds of central white matter (*black area*) insinuate themselves into cortical gray matter (G). s = subarachnoid space; K = skull; sl = sulcus. Border between white and gray matter is "gray-white interface." Central white matter describes shape of porcupine with belly directed medially.

Fig. 2.—Normal contrast scans. Transverse axial plane above lateral ventricles. Mid (**A**) and high (**B**) convexity cuts. White and gray matter clearly differentiated.
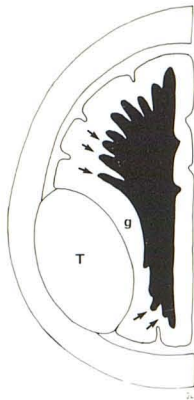

Fig. 3.—CT gray-white matter changes associated with laterally placed extraaxial masses ("white matter buckling"). Preservation of gray matter (g) and gray-white interface. White matter fronds (*arrows*) crowded together. White matter is compressed, despite presence of edema, and buckled adjacent to lesion.
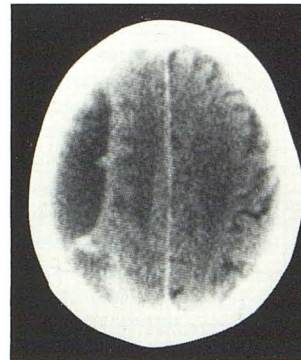

Fig. 4.—Chronic right convexity subdural hematoma in 70-year-old man with mild left hemiparesis. Typical noncontrast scan. Typical chronic subdural hematoma bordered medially by gray matter. Gray-white interface maintained. White matter clearly compressed.

matter may, therefore, have the same attenuation value as white matter or may differ from it by up to 15 or more Hounsfield units (H) (George et al., unpublished data).

Gray-White Matter Changes with Superficially Placed Extraaxial Masses

White matter changes characteristic of extraaxial masses may be seen in a variety of lesions. When the diagnosis is obvious from the character of the lesion itself, such changes are frequently overlooked. In the presence of a superficially situated extraaxial mass, cerebral edema which may be quite extensive, predominantly involves the white matter. Overlying gray matter is spared and the gray-white interface is maintained (fig. 3). Therefore, the extraaxial mass displaces the gray-white interface simultaneously compressing and buckling central white matter (fig. 3). The preservation of the gray-white interface is often best shown after injection of contrast material. The fronds of white matter are typically thinned and crowded together in contradistinction to the dilated, often separated fronds associated with malignant processes. Fronds may be dilated and crowded in association with both types of lesions, but actual inward compression ("buckling") is characteristic of extraaxial lesions only.

Three typical cases, (1) chronic convexity subdural hematoma (fig. 4), (2) an acute epidural hematoma (fig. 5), and

(3) a high convexity meningioma (fig. 6), are included in this report to illustrate the associated gray-white changes. In all cases the gray-white interface is preserved and the cortical gray matter adjacent to the extraaxial lesion is clearly seen. Central white matter is compressed and/or buckled in all cases.

Gray White Matter Changes with Superficially Placed Intraaxial Masses

Superficially situated malignancy also produces edema of adjacent white matter for the most part sparing cortical gray matter despite the presence of tumor. Central white matter and its fronds appear expanded and decreased in attenuation value (figs. 7 and 8). Parts of cortex beyond the immediate vicinity of the tumor are of normal width. In addition, adjacent to the tumor site, the gray-white interface disappears (figs. 7 and 8B). The tumor appears bathed by edema. Thus, superficially situated intraaxial masses do not visibly compress adjacent white matter (see Mechanism of White Matter Buckling).

Mechanism of White Matter Buckling

Intracranial masses cause displacement either by virtue of their own bulk, the mass effect of their associated edema, or a combination of mass and edema. We speculate that the
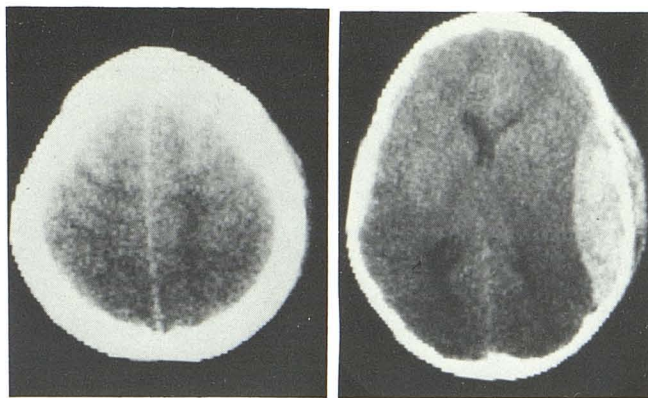
A   B

Fig. 5.—Left convexity epidural hematoma. Typical noncontrast scans. Lesion is entirely typical in mid-convexity cut (B); associated changes of gray-white matter seen in high convexity cut (A). White matter only slightly buckled but definitely compressed and medially displaced.
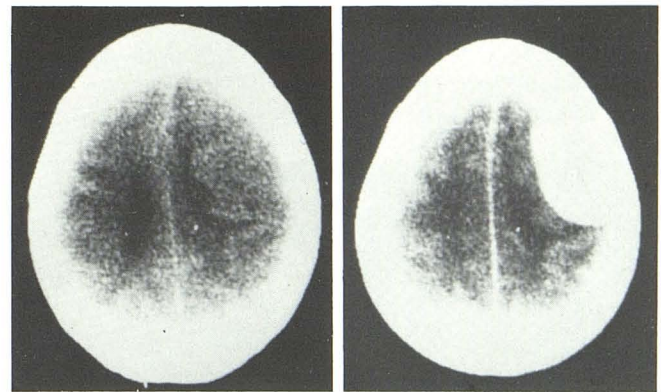

A   B

Fig. 6.—Left high convexity meningioma. A, Before contrast. Buckling of white matter anteriorly is difficult to appreciate. B, After contrast administration. Intact gray matter medial to lesion and white matter buckling are clear. Because gray matter and lesion are of same density before contrast injection, noncontrast scan of this extraaxial lesion (A) and intraaxial lesion in fig. 8A (before contrast) appear quite similar.

Fig. 7.—CT gray-white matter changes associated with laterally placed intraaxial masses. White matter (dark area) is expanded. Its fronds (arrows) are thickened by edema. At level of tumor (T), gray-white interface has disappeared. Tumor is "bathed" by white matter edema.
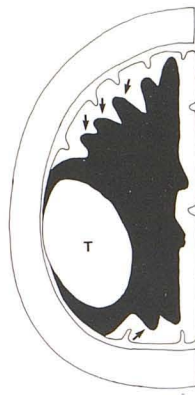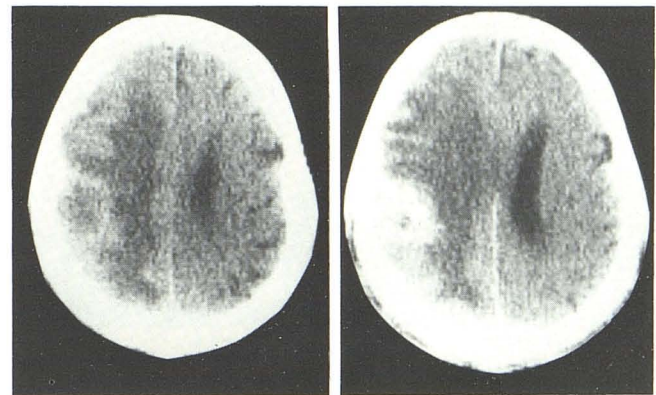
Fig. 8.—Right parietal metastasis. Before (A) and after (B) contrast administration. Laterally placed mass associated with extensive white matter edema. Expansion of white matter fronds and disappearance of gray-white matter interface. Lesion is "bathed" by white matter edema (cf. fig. 6).

7

8A   8B

phenomenon of white matter buckling is in part due to the generally accepted concept in neuropathology of the relative sparing of gray matter by edema [15–19]. Cerebral edema, especially when secondary to a mass lesion, predominantly involves the white matter [15–19]. In contradistinction, edema of viable cortical gray matter is much less common, less significant, and tends to involve small areas of tissue [15–19]. Even in the presence of severe white matter edema, overlying cortex appears normal pathologically and on CT.

Extraaxial lesions cause compression and buckling of white matter by actual displacement of the cortex adjacent to the lesion. The preservation of the gray-white interface, often best shown after injection of contrast material, permits identification of white matter compression and buckling.

If gray matter were susceptible to edema then all superficially situated lesions whether intra- or extraaxial would tend to compress and buckle white matter as a result of the mass effect caused by the swollen cortex. The question then arises as to why the malignancy itself does not cause compression or buckling by virtue of its own bulk. We postulate that this is due to the tendency of intraaxial masses to destroy the gray-white interface and to widely infiltrate the adjacent edematous white matter so that central white matter does not appear compressed or buckled on CT.

Not all extracerebral masses produce buckling of white matter. In the presence of extensive central edema, the outward force on the gray-white interface may overcome the inward force of the extraaxial mass preventing compression and buckling. In such cases, the edema pattern is indistinguishable from that of a malignant process (fig. 9). Therefore, the presence, but not the absence, of buckled white matter is diagnostically significant.

The age of the lesion is also apparently a factor. White matter buckling is almost invariably demonstrated in cases of acute and chronic extracerebral collections. It is less often discernible in association with meningioma. The importance of scan quality should also be stressed. The incidence of visualization of white matter buckling increases with scan quality and improved anatomic detail.

Materials and Methods

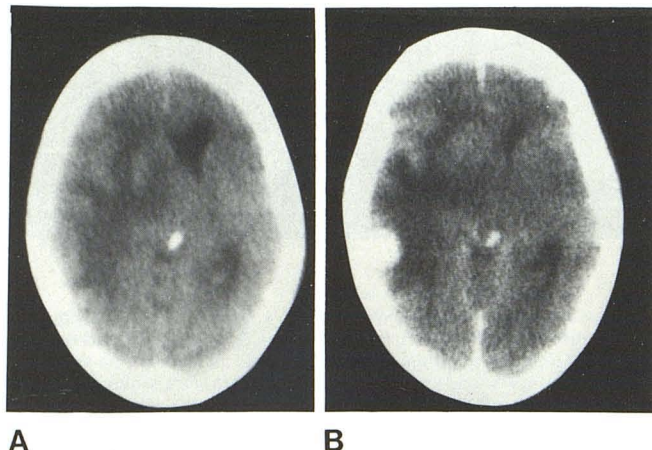In order to establish the incidence of white matter buckling in association with meningioma, a series of 100 consecutive proven meningioma cases was reviewed. In table 1, note that compression and/or buckling of central white matter was demonstrated in 14 of 17 (82%) lateral convexity, three (33%) of nine high convexity, four of 10 (40%) pteryonal, and five (42%) of 12 falcine cases. White matter buckling was not visualized in any of the subfrontal, subtemporal, medial sphenoid wing, or posterior fossa cases. The overall incidence was 28%; incidence within the group of superficially placed lesions, including the medial sphenoid wing cases, was 34%. The incidence of white matter buckling in superficially situated meningiomas, excluding the medial sphenoid wing cases, was 40% (28/70).

A   **B**

Fig. 9.—Right parietal convexity meningioma. Before (**A**) and after (**B**) intravenous contrast administration. Florid white matter edema associated with the small extracerebral mass. No evidence of white matter buckling.

Representative Case Reports

In the following atypical cases, white matter buckling was instrumental for correct localization of the extraaxial lesion.

Case 1

The CT scan (fig. 10) of a middle-aged woman demonstrates a hemorrhagic enhancing right frontal ringlike lesion with extensive associated edema. Angiography showed abnormal vascularity derived primarily from the right middle cerebral artery but also in part from the right middle meningeal artery. Prominent early draining veins were noted. On the basis of the CT and angiographic findings, the lesion was believed to be most likely a malignant hemorrhagic intraaxial process. However, the highest CT cut (fig. 10C) demonstrated the gray-white interface to be intact with thin crowded fronds of white matter buckled medially. Therefore, the lesion was correctly localized to the extraaxial compartment and at surgery proved to be a hemorrhagic meningioma.

TABLE 1: **Incidence of White Matter Buckling in Association with Meningioma**

Location of Lesion	No. Lesions	No. Lesions with White Matter Buckling	Incidence (%)
Sphenoid wing; medial	12	0	0
Sphenoid wing; lateral (pteryonal)	10	4	40
Lateral convexity	17	14	82
High convexity and parasagittal	9	3	33
Subtemporal	2	0	0
Posterior fossa	2	0	0
Tentorial	22	2	9
Subfrontal and parasellar	14	0	0
Falcine	12	5	42
Totals	100	28	28

Case 2

The CT scan (fig. 11) of this patient demonstrates a round left parietal convexity mass with intense enhancement and associated white matter edema. The lesion is seemingly within brain parenchyma and its attenuation value and enhancement are not inconsistent with a malignant intraaxial tumor. Angiography demonstrated stretching of left middle cerebral artery branches, but otherwise was not helpful. Evaluation of CT cuts immediately adjacent and superior to the lesion revealed medial compression of white matter. White matter fronds are thinned, crowded, and buckled medially and anteriorly (figs. 11C and 11D). The lesion was thereby correctly

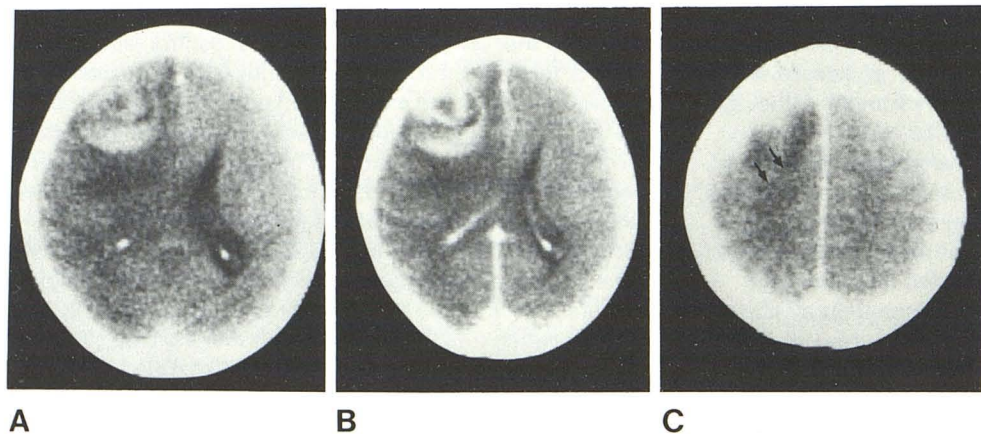**A**   **B**   **C**

Fig. 10.—Atypical right frontal convexity meningioma. **A**, Before contrast. Lesion is hemorrhagic with blood-fluid level. **B**, After contrast. Enhancement with zones of low density. **C**, High convexity cut after contrast. Buckling of gray matter faintly visualized anteriorly (*arrows*).
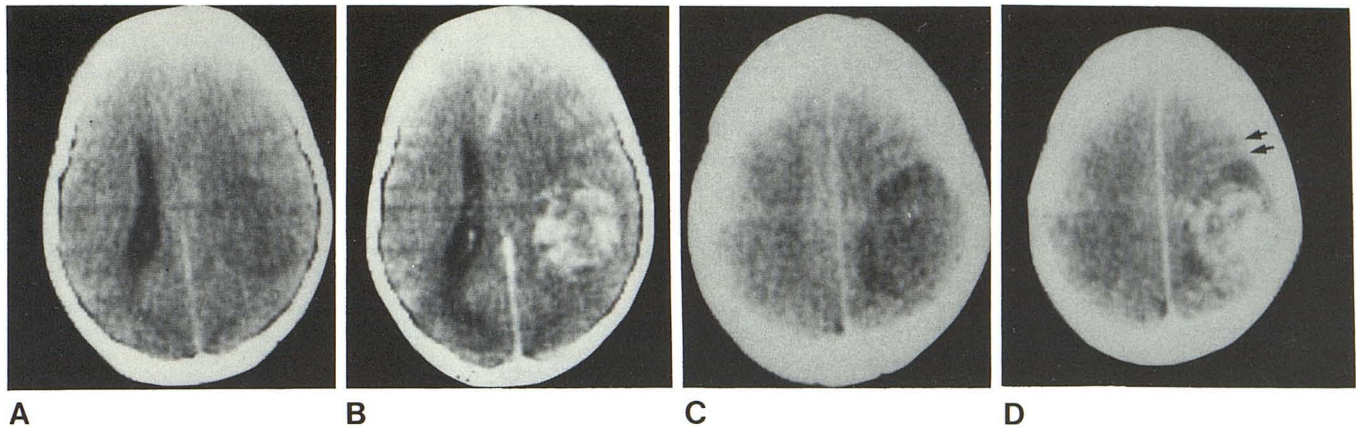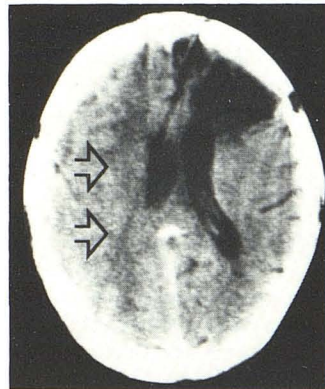
A　　　　B　　　　C　　　　D

Fig. 11.—Atypical left parietal meningioma with lipomatous elements. Before (A and C) and after (B and D) contrast. Lower cuts (A and B) reveal enhancing mass seemingly within brain parenchyma. High convexity cuts (C and D), especially after contrast (D), clearly reveal crowded displaced white matter fronds (white matter buckling).

Fig. 12.—Right isodense subdural hematoma. Contrast scan in metastatic disease suspect. Bifrontal craniotomies. Evidence of left frontal lobectomy. Right-sided white matter compression and buckling (arrows). Gray-white interface maintained.
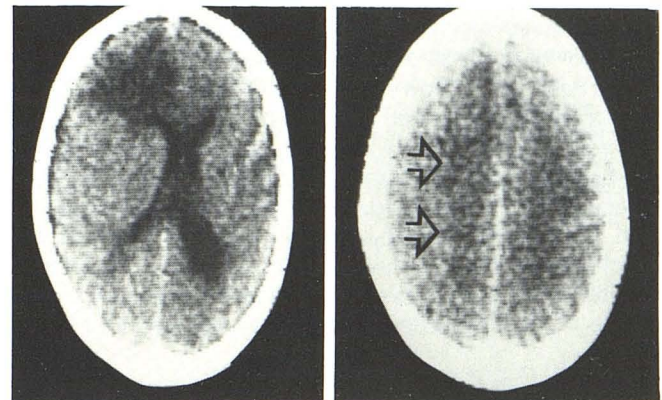

A　　　　B

Fig. 13.—Isodense subdural hematoma, contrast scans. A, Lateral ventricle level. Right frontal contusion of undetermined age. Compression of right lateral ventricle. Right to left shift. B, Convexity level. Compression and medial displacement of central white matter (arrows) consistent with extracerebral mass. Large right subdural hematoma confirmed by angiography.

localized to the extraaxial compartment; a convexity meningioma with lipomatous elements was excised at surgery.

Case 3

This middle-aged man had a metastatic left frontal tumor removed 4 years before, a recurrent left frontal metastasis removed 8 months later, and a right frontal metastasis resected 6 months before his present mild left hemiparesis. The contrast scan (fig. 12) reveals medial displacement of the entire right gray-white interface and compression of white matter indicative of a diffuse extracerebral mass, such as an isodense subdural hematoma. A large chronic high convexity subdural hematoma was demonstrated by angiography and drained at surgery with full recovery.

Case 4

This young man sustained severe head trauma. Figure 13A demonstrates a right frontal contusion of undetermined age and compression of the right lateral ventricle with a shift from right to left. The question as to whether the right frontal lesion is responsible for the shift or whether it is due to another lesion such as an isodense right extracerebral collection is answered in figure 13B, which demonstrates medial compression of white matter, indicating that the mass effect is due to an extracerebral lesion rather than the frontal contusion. An extensive right subdural hematoma was confirmed by angiography.

Discussion

Buckling of white matter may be associated with any superficially situated extraaxial mass, commonly meningioma and extracerebral fluid collections. The appearance of these lesions is usually quite typical (figs. 4–6); however, identification of buckled white matter has proven very helpful in the correct localization to the extraaxial compartment of atypical meningiomas (figs. 10 and 11) and isodense subdural hematomas (figs. 12 and 13), where the diagnosis was not otherwise obvious.

Despite extensive attention in the literature, the CT diagnosis of subdural hematoma is still often difficult [3–9, 20].

Forbes et al. [5] reported 16% total false-positive and false-negative subdural hematoma diagnoses and did not find contrast scans helpful in diagnosing subdural hematomas. They concluded that "if the patient with acute head trauma has a negative plain CT scan, nothing is to be gained by using contrast" [5]. On the other hand, recent reports have stressed the usefulness of contrast scans [7], delayed contrast scans [20], and coronal views [10] in the identification of isodense subdural hematoma. We agree with Hayman et al. [7] that double-dose contrast scans are very helpful in doubtful cases. Furthermore, contrast scans and especially double-dose contrast scans offer optimal gray white differentiation and, therefore, facilitate the demonstration of white matter buckling.

The appearance of edema associated with extraaxial lesions may be a source of confusion. Cerebral edema secondary to trauma may be quite different in appearance from edema associated with intracranial tumors [21]. Forbes et al. [5] reported that 80% of their cases with subdural hematoma were "without evidence of adjacent brain edema." Zimmerman et al. [11] reported general cerebral swelling as the most frequent CT finding in a group of 100 children with acute head injury. However, actual brain attenuation values were only slightly altered (increased). This was attributed to hyperemia associated with generalized swelling [11]. It is evident that the appearance of trauma-related cerebral edema is subtle in comparison with tumor-associated edema and it is often difficult in a trauma case to determine how much mass effect is due to cerebral edema. Therefore, identification of white matter buckling gains greater significance in identifiying the presence of extracerebral hematoma.

Superficially situated extraaxial masses usually preserve the gray matter–white matter interface seen on good quality CT scans and tend to compress and/or buckle edematous white matter. Intact gray matter is visualized adjacent to the region. This buckling of white matter does not occur with intraaxial lesions and is essentially diagnostic of an extraaxial mass. In diagnostically difficult cases, buckled white matter has proven extremely helpful in characterizing and/or identifying the presence of an extracerebral mass.

In the presence of florid white matter edema, an extraaxial mass may not exhibit buckling of white matter and may mimic the appearance of malignancy. Therefore, the presence, but not the absence, of white matter buckling is helpful diagnostically.

Buckled white matter is almost invariably associated with acute as well as chronic extracerebral collections. It is less commonly seen in association with long-standing lesions such as meningioma. White matter buckling was observed in 28 of 100 consecutive meningioma cases, including 28 (40%) of 70 superficially situated lesions.

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