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Head Trauma: Comparison of MR and CT—Experience in 100 Patients

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The results of CT and MR imaging were reviewed retrospectively and compared in 100 patients who experienced clinically significant head trauma. The findings were analyzed on the basis of several parameters in an attempt to establish objective clinical guidelines for the use of each diagnostic technique. CT remains the screening method of choice in evaluating acute severe head trauma; however, MR revealed additional clinically relevant findings in all four cases in which the patient's clinical symptoms were disproportionate to the CT findings. MR was equal or superior to CT in the evaluation of all patients with acute minor head trauma and in 94 of 95 patients examined in the subacute, chronic, or remote phase of injury, irrespective of the severity or pathologic nature of their injuries. All subacute contusions (21 lesions) and white-matter shearing lesions (18 cases) were demonstrated to particular advantage on MR compared with CT, as were all subdural hematomas (of 52 small subdural collections, 58% were detected only by MR).

Although surgical management was not altered by the additional information provided by MR, the implications regarding the medical management and disposition of the patients with head trauma were significant.

Acute traumatic injury represents a major health problem in the United States; it is the most common cause of death in individuals under the age of 45 years and the third leading cause of death in the general population [1]. The role of the radiologist in evaluating the acutely injured patient has been an ever-increasing one, particularly since the advent of CT in 1972. More recently, the introduction of MR imaging as a diagnostic method has further enhanced the potential contribution of the radiologist to patient assessment and management.

Our project was undertaken to better define the respective roles of MR and CT in the evaluation of acute and chronic sequelae of head trauma. We retrospectively evaluated and compared the CT and MR findings in the initial 100 patients who had a history of clinically significant head trauma and were examined with both techniques. This report addresses the relative merits of these imaging techniques relative to several clinical variables.

Materials and Methods

The initial 100 patients studied to evaluate the sequelae of head trauma who underwent both CT and MR examinations were included in the series. Abnormal findings on CT and MR were identified and evaluated independently by two senior attending neuroradiologists, and results were averaged for a final score. Since most cases were well known to both radiologists, there was no attempt to perform the study in a blinded manner. CT and MR examinations were evaluated together, and the presence and degree of anatomic distortion were assessed and directly compared. Lesion conspicuity (intensity/density relative to adjacent tissue) was also noted and graded on a scale of 0 (inapparent) to 4 (marked contrast). Comparison of the CT vs MR scan for each lesion and/or patient led to one of five conclusions and corresponding final scores: (1) abnormalities were identified on CT but missed on MR; (2) abnormalities were

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identified on both CT and MR, but CT provided more extensive and/or accurate characterization of the lesions; (3) MR and CT were equally efficacious in identifying the existence, nature, and extent of the abnormality; (4) abnormalities were identified on both CT and MR, but MR provided more extensive and/or accurate characterization of the lesion; and (5) abnormalities were identified on MR but missed on CT. Note was made when CT and MR provided distinct but complementary information that was relevant to diagnosis and management. For example, in one patient studied within 72 hr of injury, MR failed to identify the presence of subarachnoid hemorrhage but more accurately characterized the extent of associated parenchymal injury. The data were subdivided and analyzed with respect to several clinical variables as described below.

Clinical Extent of Injury

A *minor* injury was defined as one that resulted in no objective neurologic deficit, with or without loss of consciousness for up to 5 min. Included in this category were 24 patients with "posttraumatic syndrome," a constellation of complaints that included headache, vertigo, memory loss, attention deficits, and emotional instability, with no known associated structural CNS lesion [2]. A *moderate* injury was associated with loss of consciousness for up to 5 min and resulted in an identifiable focal neurologic deficit of a transient or permanent nature. A *severe* injury was associated with prolonged loss of consciousness and permanent neurologic impairment.

Time from Injury

Injuries were categorized as *acute* (less than 72 hr before examination), *subacute* (3–10 days before examination), *chronic* (11–30 days before examination), or *remote* (more than 30 days before examination).

Age of Patient

The patients' ages were divided into the categories of infancy (0–1 years), childhood (1–10 years), adolescence (11–20 years), young adulthood (21–40 years), middle age (40–60 years), and elderly (over 60 years).

In addition, CT and MR were compared in the context of the location and nature of the specific lesions encountered; that is, extraaxial (subdural hematomas, epidural hematomas, and subarachnoid hemorrhage) and intraaxial (contusions, hemorrhagic and bland; white-matter shearing injuries; and atrophy/encephalomalacia). Since pathologic correlation was rarely obtained, in most cases diagnoses were made on the basis of standard radiographic criteria. Subdural and epidural collections were defined as fluid collections interposed between dura and adjacent brain or bone, respectively. A contusion was defined as an area of abnormal attenuation/intensity whose anatomic location and configuration conformed to the known radiographic and pathologic features of these lesions [3, 4]. The presence of hemorrhage was inferred when the contusion contained foci of high attenuation on nonenhanced CT and/or increased signal relative to gray and white matter on both short and long TR sequences (subacute) or marked hypointensity on long TR scans only (acute) [5, 6].

Foci of white-matter abnormality presumed to be of traumatic origin were limited to two groups: (1) young patients (less than 50 years) with acute posttraumatic onset of severe neurologic compromise and no history of antecedent white-matter disease and (2) patients of any age with isolated corpus callosal foci and no prior history of demyelinating disease. White-matter lesions in patients

over age 50 who had acute posttraumatic onset of severe neurologic compromise were considered to be indeterminate in origin due to their common incidental occurrence in the elderly population [7].

CT scanning was performed on a GE 8800 scanner. Images were obtained in the axial plane at 10-mm intervals, without contrast enhancement in all cases except one in which a history of remote trauma was not elicited until after the CT examination was performed. MR studies were performed on a Teslacon* unit with a 0.5-T magnetic field, 192 × 128 matrix, two excitations, 7-mm slice thickness, and 3-mm gap. Short TR/short TE scans, 500/30 (TR/TE), were obtained in all cases. Long TR scans were initially performed (in 30 cases) with a single-echo technique, 1500/90. Subsequently, a multiecho technique was used, and 2000–2150/60, 120 images were obtained. MR scans were routinely performed in the axial plane; additional sagittal and coronal sections were obtained when indicated, primarily for the purpose of evaluating extracerebral hematomas.

Results

Clinical Extent of Injury

Of 36 patients with minor head injury, 33 (92%), including all 24 patients with posttraumatic syndrome, demonstrated no identifiable abnormality on either CT or MR, regardless of the time from injury (which ranged from less than 3 days to more than 30 days) (Table 1). MR was superior to CT in the remaining three cases; however, in only one of the three did it reveal disease related to the traumatic event: a small chronic subdural hematoma visible only on MR. In the other two instances, MR revealed unrelated abnormalities.

MR was found to be equal or superior to CT in 61 (95%) of 64 cases of moderate to severe head injury. This included three cases of moderate injury and one case of severe injury in which CT was completely normal, while MR demonstrated the presence of clinically significant white-matter and contusive injuries (Fig. 1). MR was inferior to CT in three (5%) of 64 due to its failure to adequately identify acute hemorrhage. MR missed the sole abnormality present in one case, that of a clinically insignificant linear skull fracture.

Time from Injury

Of the five patients scanned within 72 hr of injury, three patients with posttraumatic syndrome had normal studies

TABLE 1: MR and CT Assessment of Head Injury: Clinical Extent

Finding	No. of Cases			
	Minor	Moderate	Severe	Total
MR negative, CT positive	0	1	0	1
MR inferior to CT	0	1	1	2
MR equal to CT	33	7	4	44
MR superior to CT	1	38	8	47
MR positive, CT negative	2	3	1	6
Total	36	50	14	100

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Fig. 1.—23-year-old woman, mildly lethargic 6 days after head trauma.

A, CT scan is normal, as was short TR scan (not shown).

B, Long TR image, 1500/90, shows focal area of high signal in left frontal lobe, representing bland contusion.

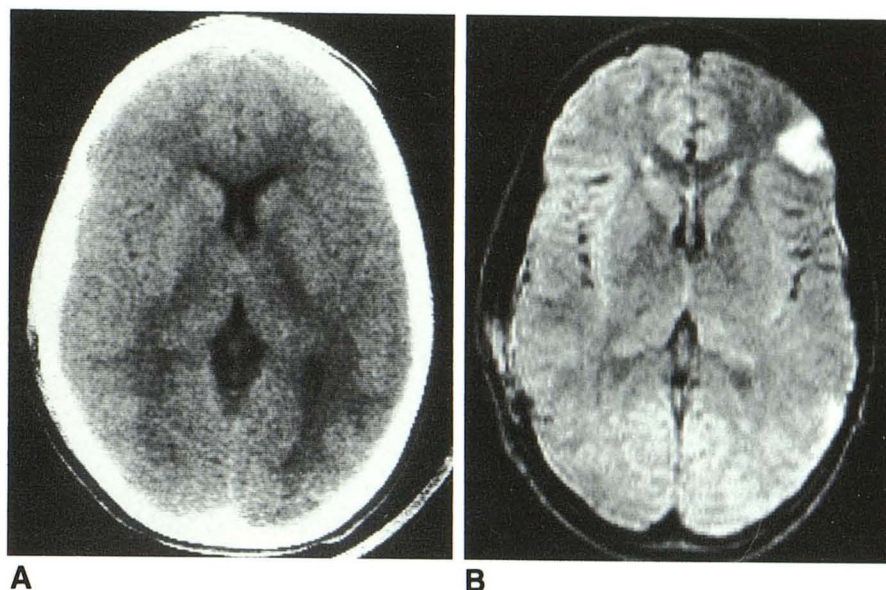


TABLE 2: MR and CT Assessment of Head Injury: Time from Injury

Finding	No. of Cases				Total
	<72 hr	3–10 days	11–30 days	>30 days	
MR negative, CT positive	0	0	1	0	1
MR inferior to CT	2	0	0	0	2
MR equal to CT	3	5	14	22	44
MR superior to CT	0	20	5	22	47
MR positive, CT negative	0	4	0	2	6
Total	5	29	20	46	100

(Table 2). In the other two patients, CT proved to be of greater value than MR because of the failure of MR to identify the presence of subarachnoid hemorrhage (both cases) or the hemorrhagic extent of a large contusion (one case) (Figs. 2A–2E). MR did offer important complementary information in both cases, providing better delineation of the presence and extent of white-matter shearing injuries and small extraaxial collections.

MR was equal or superior to CT in all 29 cases of subacute injury. In four patients, MR demonstrated a clinically significant abnormality that CT had failed to disclose, thereby revealing a heretofore occult source of the patient's neurologic impairment. These included a subtemporal subdural hematoma (Fig. 3), hemorrhagic and bland contusions, and white-matter shearing injuries.

Sequelae of chronic and remote head trauma were demonstrated to equal or better advantage with MR than with CT in 65 (98%) of 66 cases studied. Abnormalities better seen on MR included subdural hematomas (Fig. 4), white-matter injuries (Figs. 5 and 6), and atrophy and encephalomalacia, as well as traumatic carotid occlusion (absence of normal signal void in petrous and cavernous portions of carotid artery, angiographically confirmed) and posttraumatic syrinx (noted

on short TR/TE sagittal MR scans of the brain); both were demonstrated in young patients via MR alone. In two cases, CT failed to identify the sole abnormality present, specifically, small subdural hematomas in one patient (Fig. 7) and an area of white-matter injury to the external capsule in another.

Type of Lesion

Extraaxial hematomas.—Within the population of 100 patients studied, 91 extraaxial hematomas were identified in 41 patients (Table 3). Six of the hematomas were extradural in location. MR was found to be equal or superior to CT in all instances of epidural hematoma; however, in no case did CT fail to identify the collection.

Eighty-five subdural hematomas were identified in 38 patients. All subdural collections were equally or better appreciated on MR than on CT. Of 85 subdural collections 32 (38%) were missed entirely on CT (Figs. 3 and 7).

When considered on the basis of size (Table 4), the value of MR in identifying the small subdural hematoma was strikingly apparent (*small* is defined as a thin collection, variable in extent, that is insufficient to cause mass effect, i.e., a "smear" subdural [8]). Thirty (58%) of 52 hematomas were

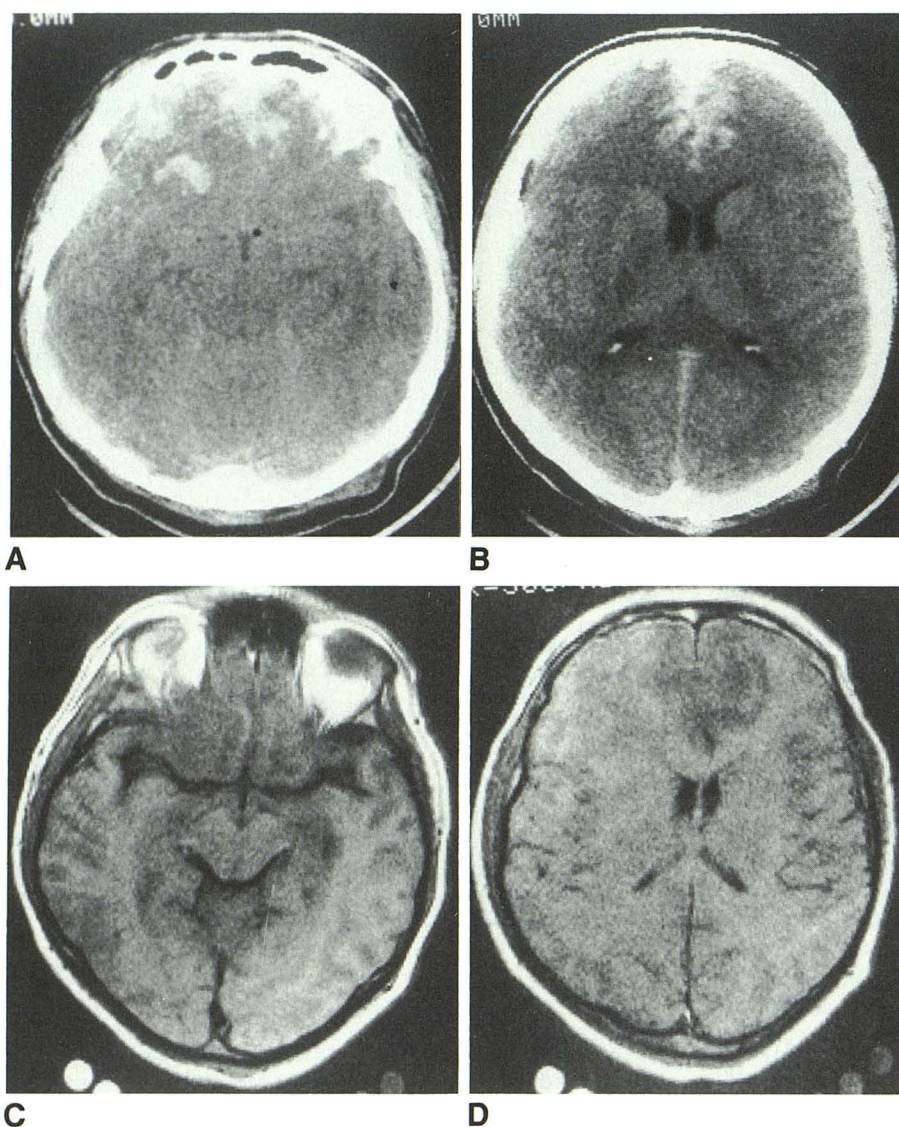


Fig. 2.—35-year-old man who fell from ladder. A and B, CT scans within 24 hr show bifrontal hemorrhagic contusions and subarachnoid hemorrhage.

C and D, Short TR images, 500/30, at 48 hr show poorly defined hypointensity at sites of parenchymal hemorrhage.

E-H are on opposite page.

not visible on CT but were well delineated on MR (Fig. 7). CT also failed to demonstrate the presence of two moderate-sized subdural hematomas: one subfrontal collection (seen on coronal MR images only) and one frontal convexity hematoma without demonstrable mass effect. Consideration on the basis of location revealed equally compelling evidence regarding the superiority of MR in selected circumstances (Table 5). CT failed to identify 14 (52%) of 27 nonconvexity subdural collections (Fig. 3).

Intraaxial lesions.—Twenty-one contusions were identified in a total of 18 patients (12 nonhemorrhagic, nine hemorrhagic) (Table 6). MR provided superior visualization in 11 (92%) of the 12 nonhemorrhagic foci and detected sites of injury that were inapparent on CT (Fig. 1) in eight (67%) of 12. With respect to hemorrhagic lesions, five (56%) of nine were better characterized by MR than by CT; in two instances of subacute injury, CT failed to identify the hemorrhagic focus entirely. Time from ictus had a dramatic effect on the ability

of MR to detect hemorrhagic lesions (Fig. 2). The initial MR study performed 48 hr after trauma demonstrated the presence of bifrontal injury, but the extent of acute hemorrhage within the contusions was more difficult to assess on MR than on CT. On follow-up examination at 3 weeks, MR revealed foci of hemorrhage that CT failed to detect. In no instance did MR fail to identify a parenchymal lesion that was visible on CT.

Thirty-three patients demonstrated MR evidence of white-matter abnormality; however, application of the previously mentioned criteria (see Materials and Methods) yielded 18 cases of white-matter disease presumed to be of traumatic origin. In 16 (89%) of 18, MR provided superior information regarding the nature and extent of shearing injury (Fig. 6). CT failed to disclose the injury entirely in 10 patients (Figs. 2H and 5).

Additional sequelae of trauma identified in 40 cases included focal atrophy, encephalomalacia, porencephaly, and

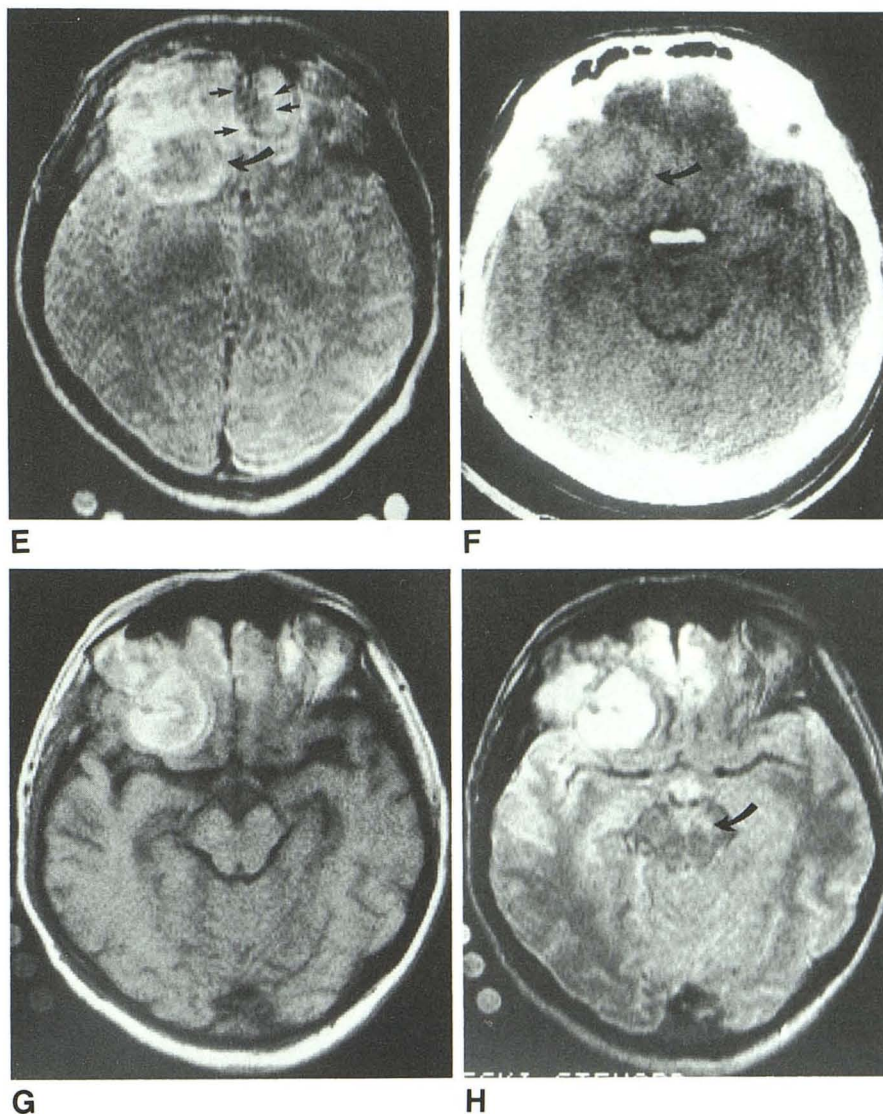
Fig. 2.—E–H.

E, Long TR image, 2000/60, is motion-degraded. Zones of hyperintensity reflect brain damage. Inner zone of mild hypointensity (curved arrow) represents acute hemorrhage. Bilateral parasagittal hemorrhages identified on CT are also mildly hypointense relative to brain (straight arrows), but because of anatomic configuration, cannot be differentiated from normal parasagittal cortex on MR alone.

F, Follow-up CT scan 3 weeks later shows only subtle evidence of previous parenchymal hemorrhage (arrow).

G, Short TR image at 3 weeks reveals hyperintense hematoma.

H, Long TR image, 2000/20. Areas of hemorrhagic and bland contusion remain hyperintense. Subtle hypointense rim surrounds aging hematoma. Hyperintense focus in left cerebral peduncle represents shearing injury (arrow).



hydrocephalus. These chronic changes were adequately defined for clinical purposes on both CT and MR; however, in 19 (48%) of 40, the multiplanar nature of MR imaging facilitated more comprehensive evaluation of injury.

Age of Patient

No significant trends were identified regarding the value of CT vs MR when the data were analyzed on the basis of the patient's age. Of incidental note, however, was the fact that the majority (59%) of patients studied were between the ages of 15 and 45 years, accurately reflecting the peak incidence of trauma in the population at large.

Discussion

As the accessibility to MR scanners has increased throughout the nation, there has been a corresponding increase in interest among clinicians and radiologists regarding the utility

of this nonionizing imaging technique in the diagnosis and management of a variety of pathologic conditions. The value of MR scanning in the identification and characterization of certain sequelae of head injury, particularly extraaxial hematomas, is well documented [8–13]. The purpose of this retrospective study of 100 patients was to establish objective clinical guidelines for the appropriate use of MR and CT, respectively, in the evaluation of patients with a history of craniocerebral trauma.

Analysis of CT and MR findings on the basis of the clinical severity of injury and time from injury showed MR to be superior to CT in all clinical settings except one: that of the acute moderate to severe head injury. In addition, while superior to CT, the value of MR in the workup of minor head trauma was limited. Although other investigators have reported good correlation between MR findings and behavioral sequelae of head injury [14], our experience did not support this claim. In all 24 cases of posttraumatic syndrome, both

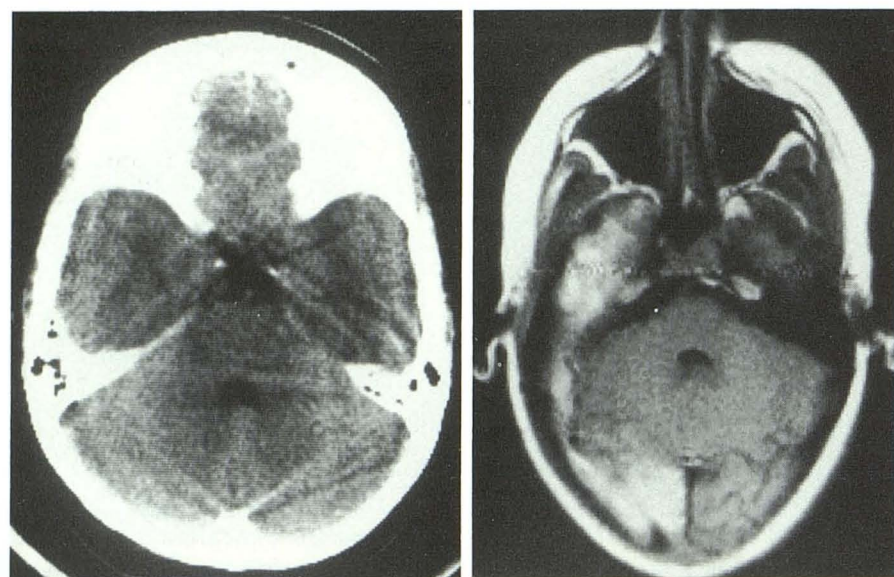


Fig. 3.—11-year-old hemophiliac with headache and mild left hemiparesis after minor head trauma.

A, CT scan through base of middle cranial fossa at 2 days is normal.

B, Short TR image, 500/30, at 5 days shows hyperintense subdural hematoma tracking along floor of middle cranial fossa and superior edge of tentorium.

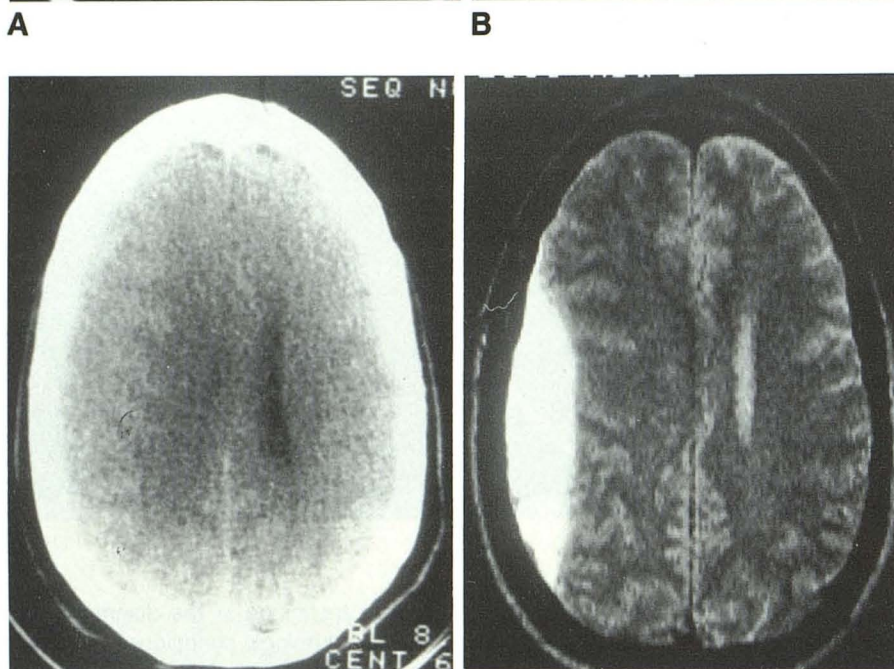


Fig. 4.—65-year-old man with fluctuating left hemiparesis studied 3 months after head trauma.

A, CT scan reveals indirect evidence of isodense subdural hematoma (marked ventricular shift and medial displacement of corticomedullary junction).

B, Long TR image, 2000/120. Subdural hematoma is directly imaged as hyperintense extra-axial collection.

techniques failed to reveal evidence of structural damage to explain its cause. However, MR did disclose lesions whose clinical manifestations can mimic those of trauma, specifically, a Chiari I malformation in one patient and multiple white-matter infarcts in another.

Two patients had acute injuries in the moderate to severe range. The small number of patients studied acutely reflects a major current limitation in the feasibility of MR scanning as an emergency procedure, namely, the logistic problems encountered with uncooperative patients or those requiring extensive monitoring or life-support equipment. These practical obstacles may be circumvented with technologic advances, such as improved monitoring and fast scanning tech-

niques [15]; however, our experience supports other investigators' assertions that CT remains the screening procedure of choice in these patients due to the failure of MR to reliably disclose the presence of acute subarachnoid hemorrhage [16–18]. In both patients, acute subarachnoid hemorrhage was readily seen on CT but was imperceptible on MR, due to its failure to produce anatomic distortion or significant alteration in the intensity of cerebrospinal fluid.

The acute parenchymal hemorrhagic lesions we studied were detected by both techniques, but CT provided superior delineation of their hemorrhagic component. The presence of low intensity on long TR images is an accepted indicator of hemorrhage, reflecting preferential T2 shortening owing to

Fig. 5.—37-year-old man in persistent vegetative state, 5 weeks after motorcycle accident.

A, CT scan fails to show focal lesion.
B, Long TR image, 1500/90, at same level reveals elongated focus of white-matter injury (short arrow). Small shear injury is also seen in body of corpus callosum (long arrows).

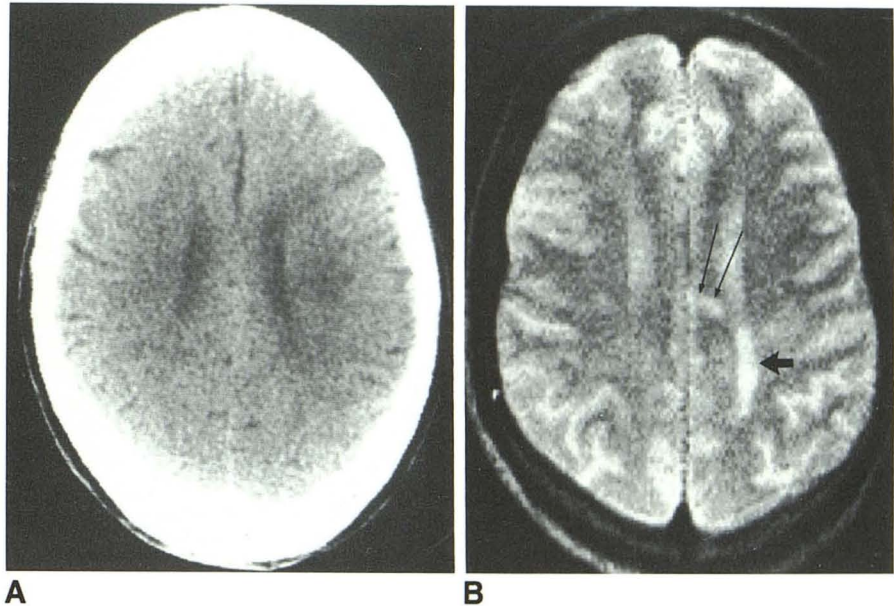
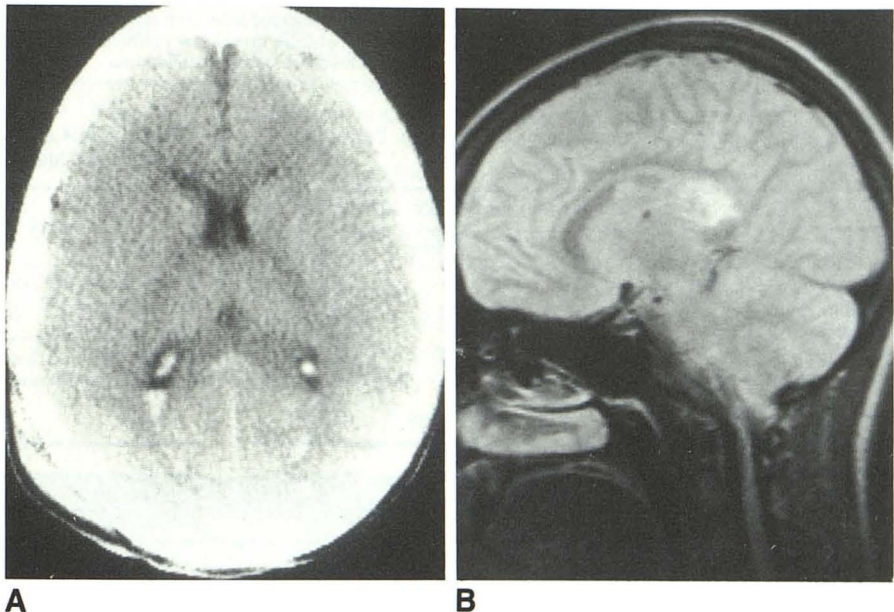


Fig. 6.—20-year-old woman, comatose after fall.

A, CT scan shows intraventricular hemorrhage and equivocal hypodensity in splenium of corpus callosum.

B, Sagittal long TR image, 2000/60, provides unequivocal evidence of shear injury involving body and splenium of corpus callosum. The patient subsequently awoke and returned to baseline mental status.



the presence of intracellular deoxyhemoglobin [6]. The extent and degree of hypointensity, however, is quite variable, and areas of hemorrhage (as identified on CT) often appear heterogeneous on MR, with zones of hyper- and hypointensity [6]. The intensity of a particular hematoma depends on a multitude of factors, both intrinsic and extrinsic, including (1) time from ictus; (2) location of hemorrhage (parenchymal, subarachnoid, or extraaxial); (3) incidence of recurrent hemorrhage; (4) degree of admixture with CSF; and (5) pulse sequence used [5, 6, 15–20].

Another extrinsic factor that affects the intensity of acute hemorrhage is field strength. In vitro studies have demon-

strated that the degree of T2 shortening produced by intracellular deoxyhemoglobin is proportional to the square of the field strength and, therefore, theoretically more apparent at a high field strength [5]. In clinical practice, hypointensity is routinely seen at 0.5 T [6], and since appropriately timed direct comparisons have not been reported, the precise implication of field strength is not known. Increasing field strength would not be expected to eliminate the problems associated with rehemorrhage into preexisting lesions, a common occurrence that further complicates the analysis of signal intensity; nor has it met with consistently greater success in the identification of acute subarachnoid hemorrhage [18].

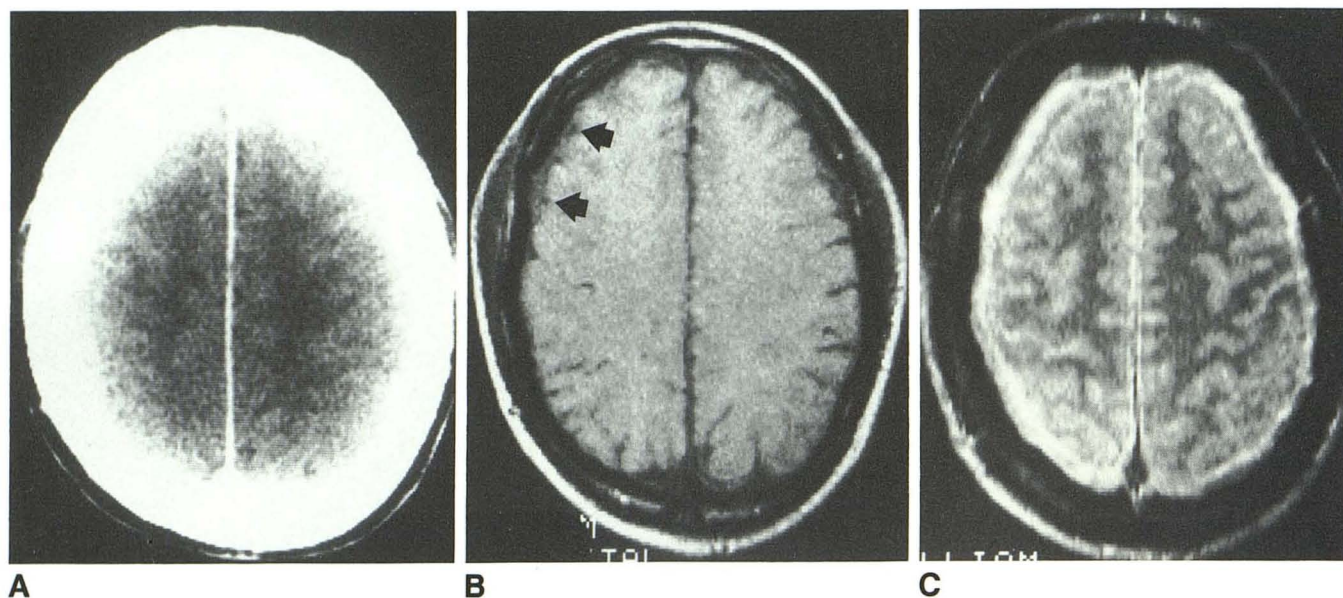


Fig. 7.—68-year-old man with presumed transient ischemic attacks and remote history of head trauma, elicited after studies were performed.

A, CT scan with IV contrast material is normal.

B, Short TR image, 500/30, at same level reveals subtle right subdural collection (note displaced veins [arrows]). Chronic nature of this hematoma is indicated by its intensity, which is only slightly greater than that of CSF, due to low methemoglobin concentration.

C, Long TR image, 2000/120, at slightly higher level shows bilateral subdural collections.

TABLE 3: MR and CT Assessment of Head Injury: Extraaxial Collections

Finding	No. of Extraaxial Collections		
	Epidural	Subdural	Total
MR negative, CT positive	0	0	0
MR inferior to CT	0	0	0
MR equal to CT	3	19	22
MR superior to CT	3	34	37
MR positive, CT negative	0	32	32
Total (no. of cases)	6 (5)	85 (38)	91 (41)

TABLE 4: MR and CT Assessment of Head Injury: Subdural Hematomas Classified by Size

Finding	No. of Hematomas		
	Small	Medium	Large
MR negative, CT positive	0	0	0
MR inferior to CT	0	0	0
MR equal to CT	6	6	7
MR superior to CT	16	15	3
MR positive, CT negative	30	2	0
Total	52	23	10

TABLE 5: MR and CT Assessment of Head Injury: Subdural Hematomas Classified by Location

Finding	No. of Hematomas				
	Convexity	Interhemispheric	Subtemporal	Subfrontal	Infratentorial
MR negative, CT positive	0	0	0	0	0
MR inferior to CT	0	0	0	0	0
MR equal to CT	12	7	0	0	0
MR superior to CT	28	4	1	0	1
MR positive, CT negative	18	6	3	2	3
Total	58	17	4	2	4

Despite these limitations, MR scanning represents a valuable adjunct to CT in the acute phase, particularly in the examination of patients whose clinical symptoms are disproportionate to the CT findings. For example, in the young woman who remained comatose after a fall (Fig. 6), MR clearly demonstrated an extensive shear injury of the corpus callosum that was poorly delineated by CT.

In the setting of subacute or chronic head injury, MR is

unequivocally superior to CT and should be the primary imaging technique whenever possible. In our review, all clinically significant lesions were adequately imaged by MR alone, and MR was more informative than CT in 53 (56%) of 95 cases; conversely, in no case did CT reveal a significant abnormality that was not apparent on MR.

Abnormalities that were seen to particular advantage on MR included subacute and chronic contusions, both bland

(Fig. 1) and hemorrhagic (Fig. 2H). The greater sensitivity of MR to subacute hemorrhage and subtle changes in water content as well as the ease of multiplanar imaging and the absence of artifacts from adjacent bone make MR the ideal imaging technique for these lesions. In addition, MR is considerably more sensitive than CT in the identification of shearing injuries (Figs. 5 and 6). However, white-matter lesions due to trauma may be radiographically indistinguishable from those associated with primary demyelinating diseases or simple aging; thus, it is necessary to apply strict criteria regarding their cause. Of 33 patients in our series with white-matter lesions, abnormalities were confidently attributed to head trauma in only 18 cases (patients under 50 years of age with acute posttraumatic onset of severe neurologic compromise and no antecedent history of demyelinating disease, and patients of any age with isolated corpus callosal foci and no prior history of white-matter disease). Among these patients, the correlation between the presence and extent of white-matter injury as identified on MR and clinical outcome was

suboptimal. Although extensive white-matter injury was consistently associated with a poor prognosis, the presence of a few foci of shearing injury was seen in patients with both poor (severe intellectual limitations and/or diminished level of consciousness) (Fig. 5) and good (Fig. 6) clinical outcomes.

Finally, MR was significantly better than CT in identifying subdural hematomas, especially small (58% missed on CT) or transversely oriented (80% missed on CT) collections, because of its superior ability to discern subtle anatomic distortion (e.g., medially displaced veins and compressed gyri) as well as the ease of multiplanar imaging. Although the subdural collections detected by MR alone were invariably nonsurgical, the practical clinical importance of identifying these small collections is well illustrated by the case of a 68-year-old patient who was admitted with a working diagnosis of transient ischemic attacks. Plans to anticoagulate this patient were deferred when small subdural hematomas, inapparent on CT, were demonstrated on MR (Fig. 7). In addition, identification of heretofore unrecognized subdural collections may have profound social implications, as in two recent cases in our institution in which the discovery of such abnormalities confirmed suspicions of child abuse (Fig. 8). Thus, while surgical management is unlikely to be altered [12], the medical and social implications may be significant.

In conclusion, we found MR to be extremely valuable in the assessment of patients with head trauma and recommend it as the primary imaging method in all patients with minor head trauma as well as in those with moderate to severe injuries in the subacute, chronic, or remote phase. Acutely injured patients with significant neurologic impairment should initially undergo CT evaluation because of the limitations of MR in the identification of acute subarachnoid and parenchymal hemorrhage; however, in selected clinical circumstances, MR represents a valuable adjunct to CT in the evaluation of these patients as well.

TABLE 6: MR and CT Assessment of Head Injury: Intraaxial Lesions

Finding	No. of Lesions by Type		
	Bland	Hemorrhagic	Shearing
MR negative, CT positive	0	0	0
MR inferior to CT	0	1	0
MR equal to CT	1	3	2
MR superior to CT	3	3	6
MR positive, CT negative	8	2	10
Total (no. of cases)	12 (9)	9 (9)	18 (18)

Note.—Bland lesions comprise nonhemorrhagic contusions and edema; hemorrhagic lesions comprise hemorrhagic contusions and hematomas.

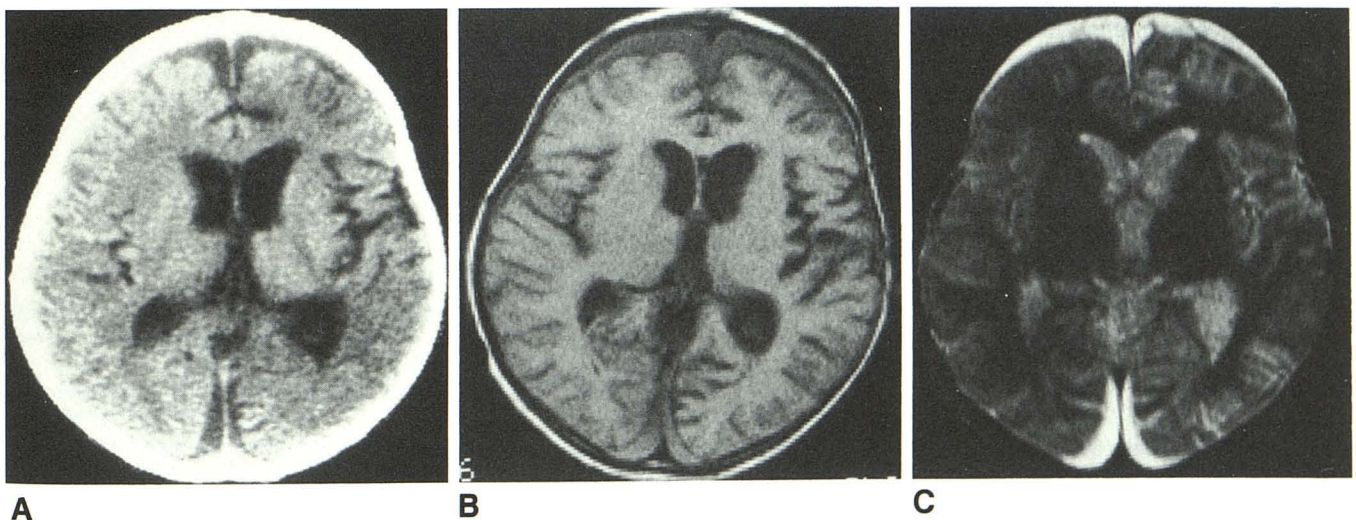


Fig. 8.—3-year-old girl, suspected victim of child abuse. A, CT scan shows evidence of atrophy; possibility of interhemispheric subdural collections vs dilated subarachnoid space was raised. B and C, MR images, 500/30 (B) and 2150/120 (C), reveal chronic interhemispheric and convexity subdural collections that are hyperintense relative to CSF on both sequences. Gyri are compressed and cortical veins displaced.

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