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Gradient-Echo MR Imaging of the Cervical Spine: Evaluation of Extradural Disease

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A prospective study was undertaken on 204 consecutive patients comparing low flip angle gradient-echo and T1-weighted spin-echo techniques in the MR evaluation of cervical extradural disease. Four patient groups were studied with varying gradient-echo TEs (6 or 13 msec) and flip angles (10° or 60°). Images were evaluated independently for contrast behavior and anatomy, then directly compared for conspicuity of lesions. The FLASH sequences (especially with a 10° flip angle) produced better conspicuity of disease in half the imaging time. T1-weighted spin-echo sequences were more sensitive to marrow changes and intradural disease. The short TE sequence (6 msec) did not produce any diagnostic advantage over the longer TE sequence (13 msec).

A fast and sensitive MR examination for cervical extradural disease combines a sagittal T1-weighted spin-echo acquisition with sagittal and axial FLASH 10° sequences.

Since its introduction, MR has become the preferred imaging method for both intradural and extradural spinal disease [1–4]. Initial evaluation of gradient-echo (GE) techniques with short TEs (12.5 msec), single slice, and low flip angles [3–10] have demonstrated good sensitivity for extradural disease while producing a shortened examination time and a CSF myelogram effect [5–7]. GE techniques appear less sensitive to intradural disease, but the number of patients remains small [6, 8, 9].

Several questions remain unanswered regarding GE imaging. (1) While high signal-to-noise is obtained with larger flip angles, field inhomogeneities and magnetic susceptibility effects degrade image quality (especially with long echo times) [8]. Would an ultrashort TE (6 msec) in which inhomogeneity-related signal loss is minimized, make a clinically significant difference in lesion detectability as compared with a longer TE? (2) Current literature has emphasized single-slice techniques [4, 6, 8]. Can a multislice technique with a longer TR (200 msec) increase the utility of GE imaging by providing more information without degradation by slice-profile overlap or increased motion artifact? (3) Can higher flip angles (with their improved signal/noise) equal the low flip angle CSF myelogram images for detecting cervical spine disease?

To evaluate these questions, we undertook a prospective study comparing conventional T1-weighted spin-echo (SE) sequences with four multislice GE sequences with varying flip angles and TEs in the detection of cervical disease.

Materials and Methods

Two hundred and four consecutive patients with known or suspected cervical disease were prospectively studied with T1-weighted SE and GE low flip angle techniques between December 1986 and October 1987. We used surface coils and either a 1.0- or 1.5-T superconducting magnet.* Patients were studied with sagittal and axial T1-weighted SE sequences with 400/17/4 (TR/TE/excitations), 4-mm slice thickness, 50% gap, and a 256 × 256 matrix. In addition, sagittal and axial GE (FLASH) images were generated by using either

* Siemens Magnetom, Siemens Medical Systems, Inc., Iselin, NJ.

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a 10° or 60° flip angle, 200/6, 13/4 (TR/TE/excitations), 4-mm slice thickness, and 50% gap. The TE = 6 images were obtained only on the 1.5-T system. The TR = 200 GE images allowed seven slices in either the sagittal or axial plane. The TE = 13 FLASH images were in-phase at both 1.0 and 1.5 T. The TE = 6 FLASH images were opposed at 1.5 T. Time constraints did not allow axial and sagittal images of each sequence type in all patients, although SE and GE sagittal images were obtained in every patient.

Extradural disease was graded from 0 to 3 according to the following scale: 0 = normal; 1 = mild extradural disease; 2 = moderate disease, may contact cord without distortion of cord; and 3 = cord compression.

T1-weighted SE and GE images were independently evaluated by two investigators for the presence, location, and degree of extradural disease. The data were then combined to determine whether the SE or GE sequence provided the best conspicuity of disease. Presence of intradural disease and metallic artifact was also noted.

For comparison with the clinical images, a theoretical plot of signal intensity versus flip angle for a fixed TR and TE was generated on the basis of the FLASH expression:

$$S = N(H)e^{-TE/T2^*}\frac{[1-e^{-TR/T1}]\sin\theta}{1-e^{-TR/T1}\cos\theta}$$

T1 values were based on 1.5 T [10].

Results

The four groups of patients are summarized in Table 1. Twenty-three patients were normal on both the SE and GE sequences; 169 patients had extradural disease at one or more levels; and intradural disease was found in 19 patients.

Of the 204 patients studied, five GE sequences were uninterpretable. Three of these were due to large metal artifacts and two were due to motion. The image quality of the SE sequences and remaining GE sequences were all adequate for interpretation.

10° Flip Angle Sequences

One hundred five patients were imaged with a 10° flip angle and a TE of either 6 or 13 msec. The images had low-signal-intensity vertebral bodies and high-signal intervertebral disks and CSF (Fig. 1). The cortex displayed very low signal, as did the posterior longitudinal ligament; the spinal cord was of intermediate signal intensity. These signal differences allowed excellent definition of the CSF-extradural interface. Posterior osteophytes were clearly outlined as low signal intensity. The cord-CSF interface was visible but not as pronounced as with the T1-weighted SE sequences or the 60° GE sequences, because of the smaller difference in signal intensity between CSF and cord (Fig. 2).

60° Flip Angle Sequences

Ninety-nine patients were imaged with a 60° flip angle sequence and a TE of either 13 or 6 msec. The 60° sequences provided an intensity of cortex, disks, and posterior longitudinal ligament that was similar to the 10° sequences (Fig. 3).

TABLE 1: Gradient-Echo Disease Categories

	Normal	XDD	IDD	Vert	Combo	No. of Patients Imaged
10°/TE = 6	7	38	7	8	17	49
10°/TE = 13	4	49	8	9	21	56
60°/TE = 6	5	40	3	10	10	48
60°/TE = 13	7	42	1	22	21	51
Total	23	169	19	49	69	204

Note.—XDD = extradural disease, IDD = intradural disease, Vert = vertebral body changes, Combo = patients with combination of two or more disease categories.

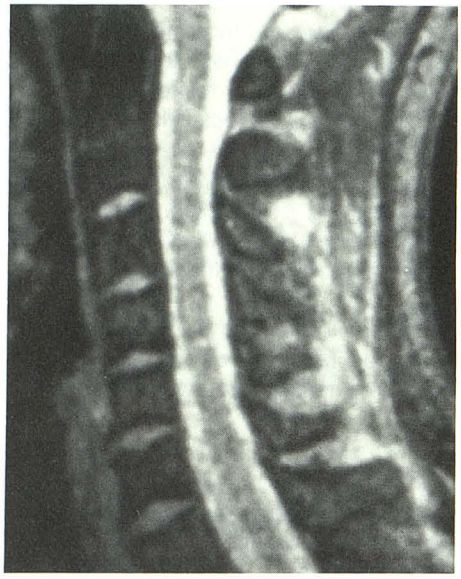

Fig. 1.—Typical appearance of 10° flip angle FLASH sagittal image with TE-6 (GE 200/6/10°).

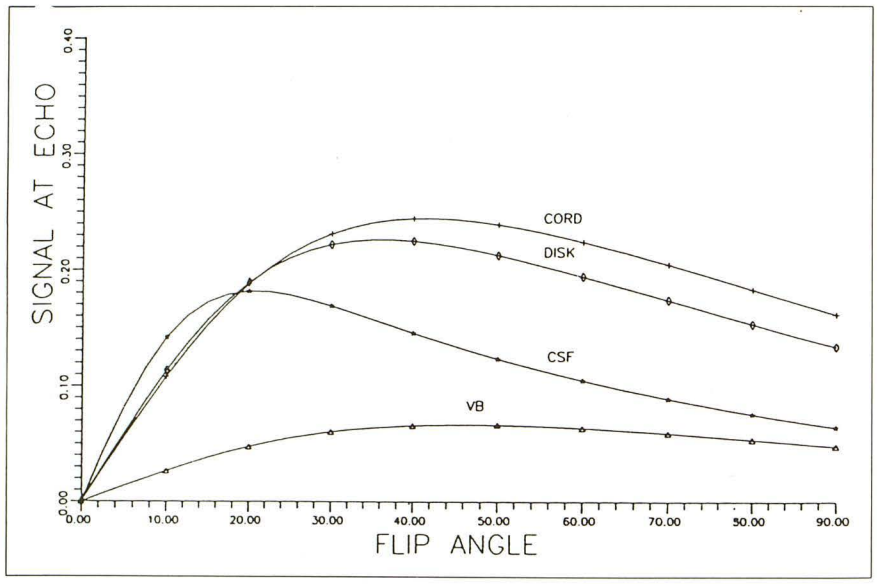

Fig. 2.—Signal intensity versus flip angle for a FLASH 200/13 sequence shows CSF myelogram effect at low flip angles and increased disk/CSF contrast with higher angles.

The 60° GE sequences had relatively low-signal-intensity CSF, which was, however, somewhat higher in signal intensity than the vertebral body cortex and posterior longitudinal ligament. The extradural-CSF interface was identifiable. The 60° sequences provided sharp CSF-cord interface because of the relative differences in signal intensity (Fig. 2).

Extradural Disease

When SE and GE images were compared, the GE images at least equaled and usually proved superior to the SE images for conspicuity of extradural disease (Figs. 4–6). Both 10° sequences (TE = 6 and TE = 13) provided an improvement in detectability of extradural disease. This was not merely detection of mild (grade 1) disease, but reflected an increase in detection of higher-grade lesions as well (Fig. 7). The 60°/TE = 13 sequence also provided an increase in conspicuity over the comparison SE sequence (Fig. 8). However, the increase in detectability was not as great as with either of the 10° flip angle groups. When the 60°/TE = 6 sequence was evaluated, it proved only equal to the T1-weighted sequence. Comparison of TE = 13 and TE = 6 sequences failed to demonstrate improvement in visual image quality or disease detection with either the 10° or the 60° flip angle. In the evaluation of extradural disease, the two TE sequences were rated as equal when a 10° flip angle was used. With a flip angle of 60°, the TE = 6 sequence was rated less efficacious in the detection of extradural disease.

The multislice techniques did not increase motion artifact and allowed for detection of lateral disks in the sagittal images

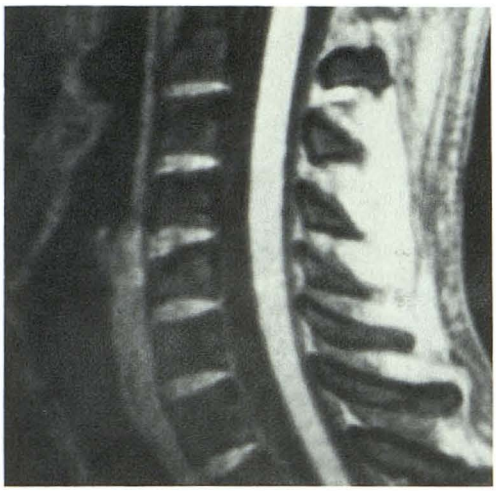

Fig. 3.—Typical appearance of 60° flip angle FLASH sagittal image with TE = 6 (GE 200/6/60°).

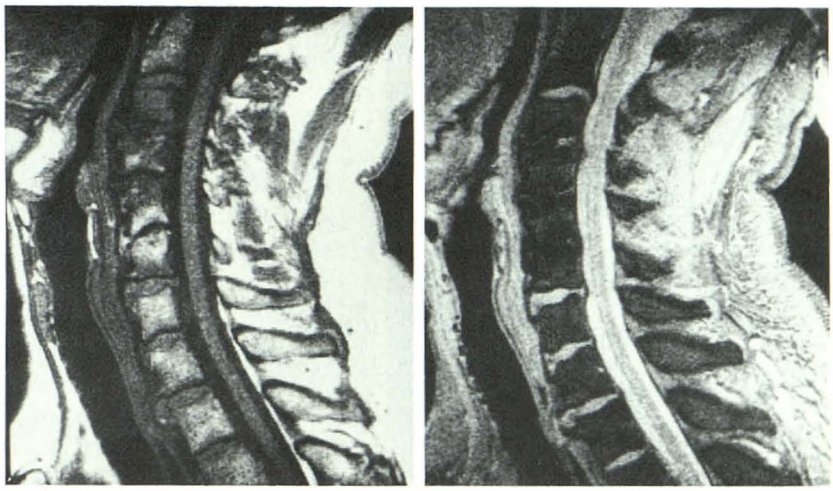

Fig. 4.—*A* and *B*, Comparison of SE 400/17 (A) and FLASH 200/13/10° (B) in a patient after C3–C4 through C5–C6 anterior fusions. Small anterior extradural defects at C2–C3 are better defined on the GE image, while C6–C7 herniation is seen equally well on both.

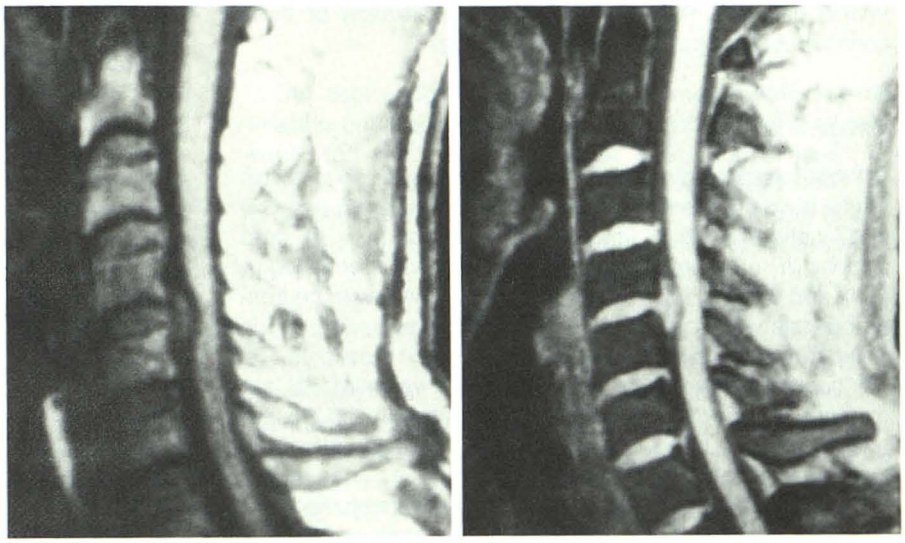

Fig. 5.—*A* and *B*, Comparison of SE 400/17 (A) and FLASH 200/6/60° (B). Large herniation (C4–C5) and small herniation (C3–C4) are seen equally well on both sequences. Small herniations seen at C5–C6 and C6–C7 on the GE study are not visible on the SE image.

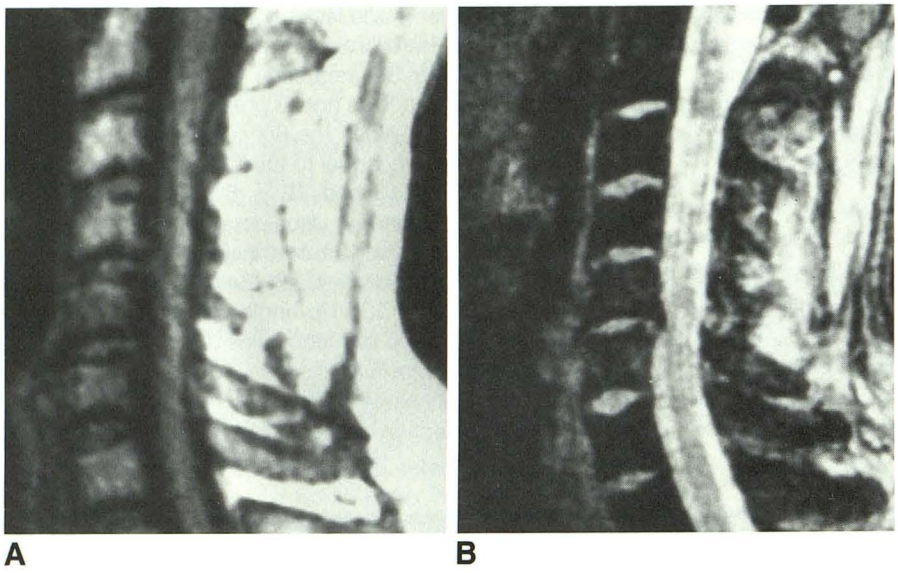

Fig. 6.—*A* and *B*, SE 400/17 image (A) is suboptimal because of motion artifact, but no gross disease is evident. FLASH 200/13/10° sequence (B) shows low signal intensity osteophyte at C5–C6 (moderate disease).

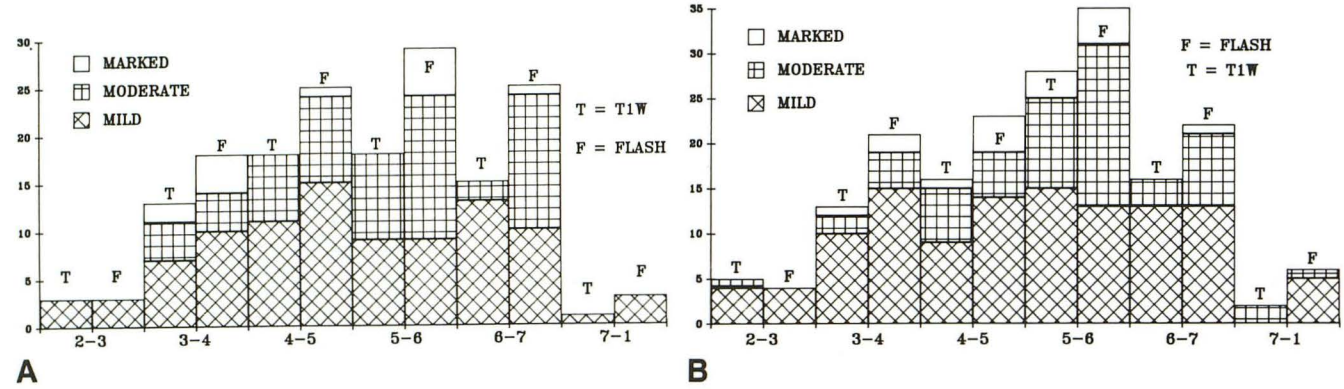

Fig. 7.—*A* and *B*, The number of extradural defects graded as mild, moderate, or marked versus the cervical disk level for SE 400/17 is compared with FLASH 200/6/10° (A) and FLASH 200/13/10° (B). The FLASH 10° sequences are superior to the SE sequence with both TEs.

in five patients. They also provided visualization of three contiguous interspaces on the axial images.

Intradural Disease

While intradural disease was not the principal focus of this study, it was present in 19 sequence pairs (i.e., SE and GE) in 17 patients—syrinx (n = 7), neurofibroma (n = 4), cord atrophy (n = 3), metastases (n = 1), Chiari I malformation (n = 1), and multiple sclerosis (n = 1). One patient with neurofibromatosis was imaged on three separate occasions and is included in all four patient groups (Fig. 9). In 13 patients 10° GE sequences were compared with T1-weighted SE sequences. Abnormalities were only visualized in the SE sequences in nine of 13 cases. In no case was the intradural disease only identified on the GE sequence.

Only four patients with intradural disease were studied with a 60° GE sequence. In all, the intradural disease was equally well seen on both the SE and the 60° GE sequences.

Metal Artifacts

Metal artifacts were present in 10 patients (Table 2). In only three GE sequences did they preclude image interpretation. In four patients metal artifacts were present on both imaging sets, but they were worse on the GE sequences. In one patient metal artifact was identified only on the GE sequence, and in another the amount of artifact was equal on both studies. In the last patient, a small amount of postsurgical metal artifact was identified only on the T1-weighted sequence. This patient had had diskectomy and fusion, and the small amount of metal artifact was missed on the GE sequence because it was obscured by the low-signal-intensity marrow.

Discussion

Although the standard SE sequences have revolutionized spinal imaging because of the noninvasive nature of MR and

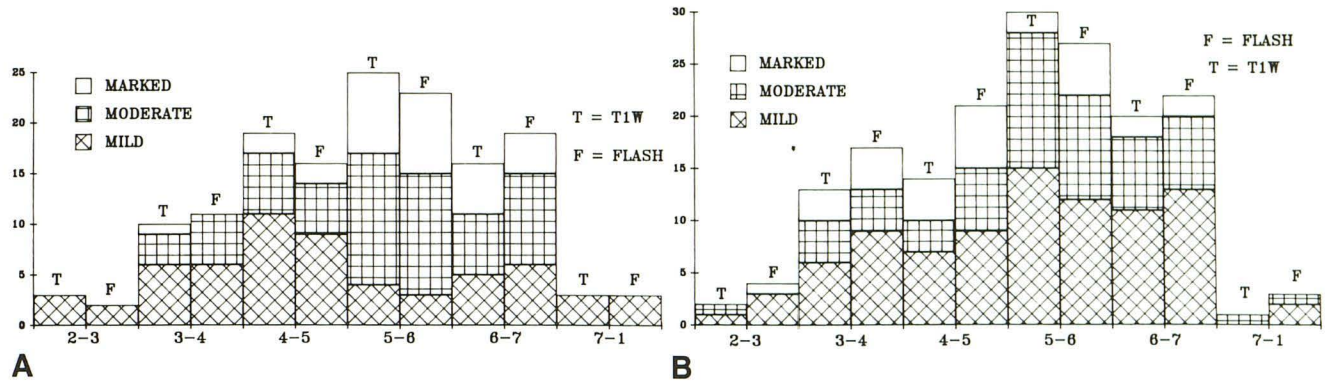

Fig. 8.—*A* and *B*, The number of extradural defects graded versus the cervical disk level for SE 400/17 is compared with FLASH 200/6/60° (A) and FLASH 200/13/60° (B). While the FLASH sequences continue to provide increased conspicuity of extradural disease compared with the SE sequence, the superiority is not as pronounced as with a 10° flip angle.

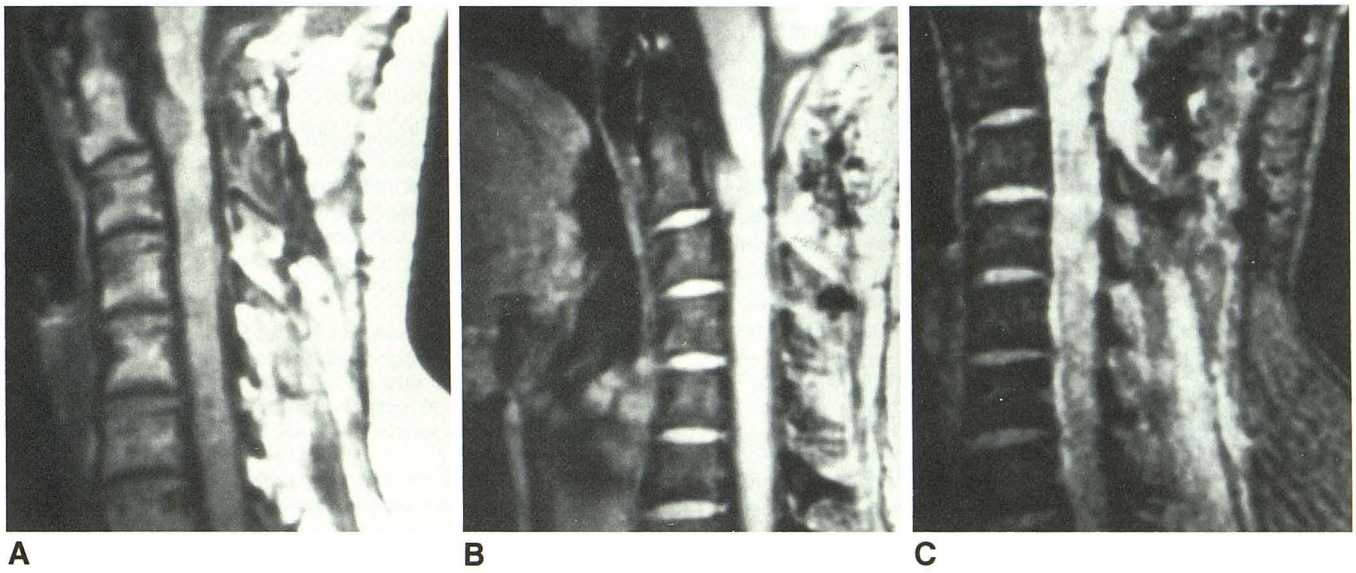

Fig. 9.—*A–C*, Neurofibroma at C2 level is well defined on SE 400/17 (A) and FLASH 200/13/60° (B) sequences. Lesion is not visible on FLASH 200/6/10° sequence (C).

TABLE 2: Metal Artifacts Identified (*n* = 10)

	T1W SE Only	GE Only	Present on Both SE and GE	Uninterpretable GE
10°/TE = 6			1	
10°/TE = 13	1	1	3	
60°/TE = 6			1	1
60°/TE = 13			3	2

Note.—T1W = T1-weighted, SE = spin echo, GE = gradient echo.

its ability to detect intradural and intramedullary abnormalities, new sequence techniques, specifically the partial flip angle techniques, offer the advantages of shortened time and increased conspicuity of extradural disease. Previous reports have stressed the importance of low flip angle, single-slice techniques and the use of short TEs [5–7, 9].

Our data support previous work demonstrating that GE imaging provides conspicuity of extradural disease at least equal to, and generally greater than, conventional T1-weighted SE techniques. A shortened examination time (approximately half that of T1-weighted SE sequences) is valuable because it decreases patient motion, increases patient comfort, and increases patient throughput.

As in the studies published by Hedberg et al. [6], a 10° flip angle was the most useful for identifying extradural disease. Both the 10°/TE = 13 and 10°/TE = 6 sequences were much more sensitive in evaluating extradural disease than were the standard T1-weighted SE sequences. The 60°/TE = 13 sequence provided some increased conspicuity over SE images, but not to the degree provided by either of the 10° sequences. The 60°/TE = 6 sequence was equal to SE sequences in identification of extradural disease. The advantage of 10° sequences is the extremely sharp CSF-extradural interface

provided by the low signal intensity of the vertebral bodies as opposed to the high signal intensity CSF. Although the CSF-extradural interface is identifiable on 60° GE sequences, the decreased signal of the CSF makes this interface, and thus extradural disease, more difficult to discern.

There appears to be a limit to the advantage of shortening the TE. Previous studies [7, 9], which used TEs from 12.3–25 msec, showed that a shorter TE provided better images and better disease identification. Our work demonstrates that further reducing the TE to 6 msec does not provide any advantage in image quality or disease detection. This failure reflects the changes in the sequences necessary to accommodate the ultrashort TE. To obtain the short TE yet maintain resolution, the sampling time must be reduced. The read gradient bandwidth is increased correspondingly, and thus there is a square root increase in the noise. Although the number of studies marred by metal artifact was too small for adequate analysis, no obvious decrease in metallic artifact was observed with the 6-msec TE. The static local field inhomogeneity associated with metal implants is so large that signal loss is significant even with TE = 6.

The single-slice sagittal techniques used previously have produced excellent images but have been unable, by their very nature, to provide information about lateral disease [5, 7, 9]. We have found that the multislice technique also yields excellent images and does not have a significant degradation in signal/noise with a 50% gap. The seven slices available adequately cover the breadth of the cervical canal in the sagittal direction, and cover three contiguous interspaces in the axial direction. In fact, five patients with lateral disks would have appeared normal on a midline sagittal slice, but were clearly abnormal on multislice GE sequences.

The GE techniques are less useful in evaluating intradural disease. We found, as have others [6, 8, 9], that intradural disease was inconsistently visualized, especially with the 10° flip angle. The reasons for this are not completely clear, as some intradural disease is well seen on 10° GE sequences. It is of interest that all four intradural processes evaluated with 60° GE sequences were clearly identified. Further investigation as to the usefulness of this type of sequence in evaluating intradural disease is needed.

We therefore feel that when the primary concern is for intradural disease, T1- and T2-weighted SE sequences, rather than GE sequences, should continue to be the imaging strategy of choice. When T1-weighted or GE sequences yield unexpected abnormalities in either the cord or vertebral bodies, a T2-weighted SE sequence should be added.

Conclusions

Low flip angle, multislice GE techniques offer advantages over T1-weighted SE imaging sequences in the evaluation of extradural disease. They produce an increased conspicuity of extradural disease with a concomitant decrease in examination time. Multislice techniques allow for evaluation of the lateral aspects of the canal as well as for multislice axial imaging.

Decreasing the TE beyond 13 msec does not offer any advantage in imaging, probably because of the increased noise produced by the compensatory bandwidth widening.

REFERENCES

1. Modic MT, Pavlicek W, Meredith WA, et al. Magnetic resonance imaging of intervertebral disk disease. *Radiology* **1984**;152:103–111
2. Modic MT, Weinstein MA, Pavlicek W, et al. Nuclear magnetic resonance imaging of the spine. *Radiology* **1983**;148:757–762
3. Modic MT, Masaryk TJ, Mulopulos GP, Bundschuh C, Han JS, Bohlman H. Cervical radiculopathy: prospective evaluation with surface coil MR imaging, CT with metrizamide, and metrizamide myelography. *Radiology* **1986**;161:753–759
4. Karnaze MG, Gado MH, Sartor KJ, Hodges FJ III. Comparison of MR and CT myelography in imaging the cervical and thoracic spine. *AJNR* **1987**;8:983–989, *AJR* **1988**;150:397–403
5. Enzmann DR, Rubin JB, Wright A. Cervical spine MR imaging: generating high-signal CSF in sagittal and axial images. *Radiology* **1987**;163:233–238
6. Hedberg MC, Drayer BP, Flom RA, Hodak JA, Bird CR. Gradient echo (GRASS) MR imaging in cervical radiculopathy. *AJNR* **1988**;9:145–151
7. Enzmann DR, Rubin JB. Cervical spine: MR imaging with a partial flip angle, gradient-refocused pulse sequence. Part I. General considerations and disk disease. *Radiology* **1988**;166:467–472
8. Winkler ML, Ortendahl DA, Mills TC, et al. Characteristics of partial flip angle and gradient reversal MR imaging. *Radiology* **1988**;166:17–26
9. Enzmann DR, Rubin JB. Cervical spine: MR imaging with a partial flip angle, gradient-refocused pulse sequences. Part II. Spinal cord disease. *Radiology* **1988**;166:473–478
10. Hardy CJ, Edelstein WA, Mueller OM. Surface-coil T1 images. *Magn Reson Med* **1986**;3:935–940