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Magnetic Resonance Imaging of the Chronically Injured Cervical Spinal Cord

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Thirteen patients with prior cervical spinal cord injury resulting in quadriplegia were evaluated with magnetic resonance imaging (MRI) long after their initial injury, either because of the relatively recent onset of new and worsening neurologic symptoms or to rule out residual compression on the spinal cord or nerve roots. The results of MRI were compared with delayed metrizamide computed tomography (CT) in 10 cases, and in five of those the results were also compared with intraoperative spinal sonography. It was found that MRI more accurately demonstrated the intramedullary abnormalities in the injured spinal cord than did delayed metrizamide CT because the former could separate myelomalacia from a posttraumatic spinal cord cyst, a differentiation that was frequently difficult with delayed metrizamide CT. T2-weighted spin-echo pulsing sequences with long echo times were particularly useful in evaluating these patients.

Over the years, the radiographic assessment of damage to a previously injured spinal cord has included Pantopaque myelography [1, 2], air myelography [3], percutaneous cord puncture [2, 3], and, most recently, delayed metrizamide computed tomography (CT) [1, 3, 4]. Of these, delayed metrizamide CT is the most accurate, because it can detect an abnormal accumulation of water-soluble contrast media within the spinal cord, which suggests the presence of either a posttraumatic spinal cord cyst [4] or myelomalacia [5]. Nonetheless, potential diagnostic pitfalls associated with delayed metrizamide CT during preoperative evaluation of a chronically injured spinal cord have been demonstrated by intraoperative spinal sonography. Specifically, abnormal intramedullary metrizamide may be present in either myelomalacia or in a posttraumatic spinal cord cyst [5]. It is desirable, therefore, to have a more dependable method of distinguishing, prior to surgery, patients with shuntable intramedullary cysts from those with chronically damaged but noncystic spinal cords.

Although a number of reports have been published on the magnetic resonance imaging (MRI) in previous pathologic processes involving the spinal cord, MRI has not, to our knowledge, been used to evaluate a series of patients with previously injured spinal cords. In this paper we report the use of MRI in 13 patients with prior cervical cord trauma, 10 of whom were also studied with delayed metrizamide CT and five of whom had surgery. It is our objective to compare the results of MRI with those of delayed metrizamide CT in order to determine which is the most accurate method of preoperatively evaluating the chronically damaged spinal cord. Further, we correlate these imaging modalities with the patients' clinical presentations and the findings at surgery as determined by intraoperative spinal sonography.

Materials and Methods

Thirteen patients who had suffered severe cervical spinal cord trauma six months to 11 years prior to their present hospitalization were evaluated clinically and examined radiograph-

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TABLE 1: Clinical Data and Imaging Results in the Chronically Injured Cervical Spinal Cord

Clinical Data					Imaging Results			
Case No.	Age at Injury (years)	Time from Injury to Present Evaluation (years)	New Symptoms	Time Since New Symptoms Appeared (months)	DMCT Dx.	Time from DMCT to MRI	MRI Dx.	Intraoperative Spinal Sonography and Surgical Findings
1	26	5	Hyperhidrosis left neck and face; paresthesias both UEs	24	Cyst	1 day	Cyst	Cyst
2	26	2.5	Decreased strength and sensation rt. hand; pain rt. UE	5	Myelomalacia	2 mo	Cyst	Cyst
3	18	11	Hyperhidrosis—bilaterally, face and neck	2	Not done (iodine allergy)	. . .	Cyst	Awaiting surgery
4	19	11	Neck and head pain in recumbent position; paresthesias both UEs	6	Cyst	1 mo	Cyst	Cyst
5	27	1.5	Increased UE and LE spasticity; hyperhidrosis	1	Myelomalacia	1 mo	Cyst	Awaiting surgery
6	16	0.5	Neck and left arm pain	2	Cyst	2.5 mo	Cyst	No surgery
7	33	1	Positional headaches; ascending sensory level	1	Cyst	1 mo	Cyst	Myelomalacia
8	16	1.5	None. Patient studied prior to anterior decompression—hopeful of increasing C6 and C7 root function		Cyst	5 days	Myelomalacia	Myelomalacia
9	15	8	None. Patient studied prior to computerized closed-loop functional electrical stimulation to R/O residual bony cord compression		Cyst	5.5 mo	Myelomalacia	No surgery
10	34	3	None. Patient studied because he plateaued neurologically after a steady improvement over 3 years		Myelomalacia	1 mo	Myelomalacia	No surgery
11	31	3	Progressive weakness, numbness, and pain in UEs; hyperhidrosis, face and neck	3	Normal	1 mo	Myelomalacia	No surgery
12	18	5	Increased numbness in distal UEs bilaterally	2	Not done	. . .	Myelomalacia	No surgery
13	15	6	Increased spasticity of UEs and LEs	2	Not done	. . .	Normal	No surgery

ically with MRI. Ten of those patients were also examined with delayed metrizamide CT. Five patients were operated on, and they were evaluated during surgery with intraoperative spinal sonography. The pertinent clinical data on each patient are summarized in Table 1.

Contiguous 5-mm axial sections were obtained with delayed metrizamide CT performed 4 to 6 hr following routine cervical metrizamide myelography. Because our objective in this investigation is to compare the intramedullary abnormalities as seen on delayed metrizamide CT with those seen on MRI, other radiographic abnormalities that may have been observed—such as adhesions or scarring, bony encroachment on the canal or cord, and canal angulation—are not included. With the exception of Case 6, the time interval between the delayed metrizamide CT and the MRI was a small percentage of the elapsed time between the initial injury and the present radiologic evaluation. For patients who had MRI more than a week following

delayed metrizamide CT, the time shown in Table 1 is the nearest half month. In two patients (Cases 12 and 13), the delayed metrizamide CTs were performed more than 2 years prior to their MRIs and are therefore not included in this comparison.

MRI was obtained in the sagittal plane on a 0.5 T superconducting magnet operating at 0.35 T over a span of 1.5 years (February 1984 through June 1985). Images 5 mm thick with 2 mm spacing were obtained by using the spin-echo (SE) technique. When necessary, interlacing with overlapping images was acquired. In the majority of cases, three T1-weighted (TR: 0.3 sec, TE: 35 msec; four averages) and 10 dual echo (five at each echo), T2-weighted (TR: 1.5 sec., TE: 35 and 70 msec; two averages) images were generated. In four cases, even longer echo times were obtained (up to 240 msec) to increase the T2 weighting. The images were acquired and displayed on a 256 × 256 matrix and reconstructed with a fast 2D Fourier transform.

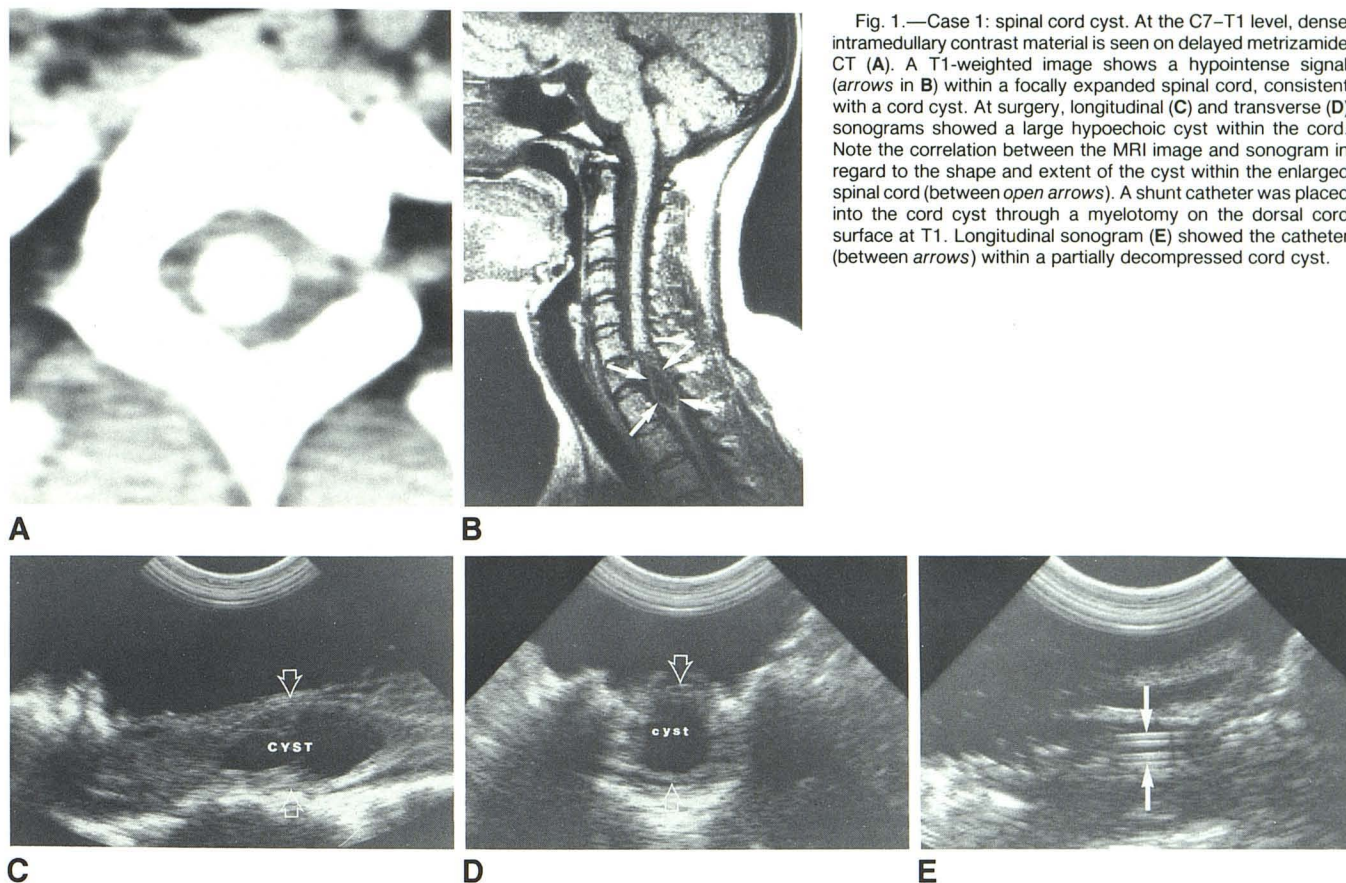


Fig. 1.—Case 1: spinal cord cyst. At the C7–T1 level, dense intramedullary contrast material is seen on delayed metrizamide CT (A). A T1-weighted image shows a hypointense signal (arrows in B) within a focally expanded spinal cord, consistent with a cord cyst. At surgery, longitudinal (C) and transverse (D) sonograms showed a large hypoechoic cyst within the cord. Note the correlation between the MRI image and sonogram in regard to the shape and extent of the cyst within the enlarged spinal cord (between open arrows). A shunt catheter was placed into the cord cyst through a myelotomy on the dorsal cord surface at T1. Longitudinal sonogram (E) showed the catheter (between arrows) within a partially decompressed cord cyst.

Results

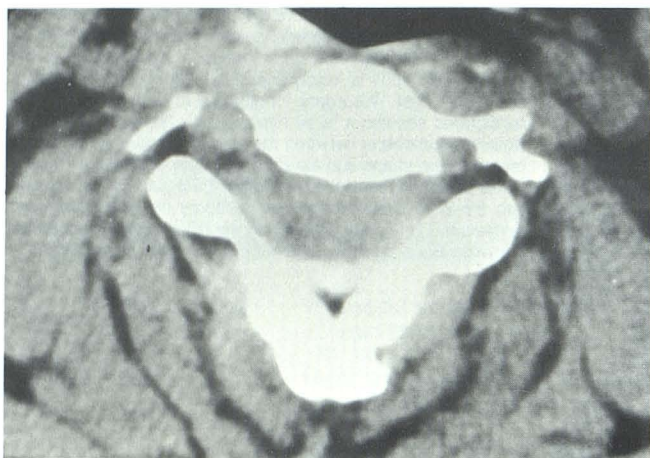
Table 1 summarizes the clinical and radiographic results in our patients.

All had suffered severe cervical spinal cord injuries, which had left them quadriplegic (10 complete, three incomplete). After a period of clinical stability ranging from six months to 11 years, 10 patients developed new symptoms, including one or more of the following: pain, increased sensory deficit, hyperhidrosis, paresthesias, and spasticity. The patients were able to recall when these new symptoms first appeared, and the time period from their first appearance to the present radiologic evaluation (1 month to 2 years) is listed in Table 1. This finding was independent of the severity and type of symptoms experienced. Development of new symptoms was also unrelated to whether the patients were complete or incomplete quadriplegics; two of the three incomplete quadriplegics (Cases 3 and 11) had new symptoms, one (Case 10) did not. Three patients (Cases 8, 9, and 10) had no new symptoms but were studied for different reasons (also indicated on Table 1).

With delayed metrizamide CT we attempted to differentiate posttraumatic spinal cord cyst from myelomalacia on the basis that the former would be more likely to show dense, well-defined intramedullary contrast extending beyond the site of original injury, whereas myelomalacia would be more likely to

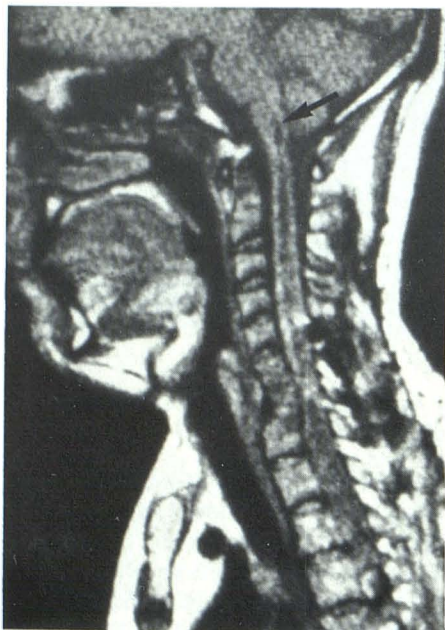
show ill-defined, less dense intramedullary contrast involving only areas of the cord adjacent to the original injury.

With MRI, the images were observed for the presence of both high- and low-intensity signals in the T1-weighted images (e.g., Fig. 1) and the T2-weighted images (e.g., Figs. 2–4). A lesion within the cord that had a low signal intensity on both the T1-weighted images (e.g., Figs. 2B and 2C) and the moderately T2-weighted images, and that had a higher signal intensity on the more heavily T2-weighted images (e.g., Fig. 2D), which paralleled the signal from the spinal fluid in the adjacent subarachnoid space, suggested the presence of cerebrospinal fluid within the cord, specifically a posttraumatic spinal cord cyst. These findings correspond to the known long T1 and T2 of cerebrospinal fluid when compared with normal spinal cord tissue. On the other hand, a lesion with low signal intensity within the cord on the T1-weighted images (Fig. 3B) that became isointense or slightly more intense than the surrounding cord on the moderately T2-weighted images (Fig. 3C), and that showed signals on the more heavily T2-weighted images (Fig. 3D), which did not parallel the signal from the cerebrospinal fluid in the adjacent subarachnoid space, suggested the presence of myelomalacia rather than a cyst. For reasons we describe in the Discussion section, whenever MRI suggested the presence of myelomalacia surrounding an intramedullary cyst, just the word "cyst" appears in the appropriate column in Table 1.

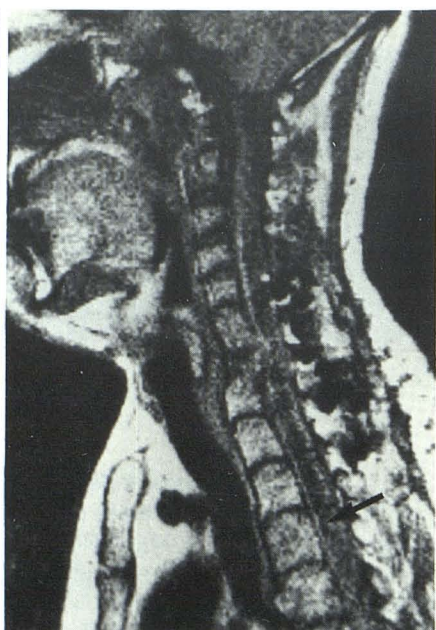


A

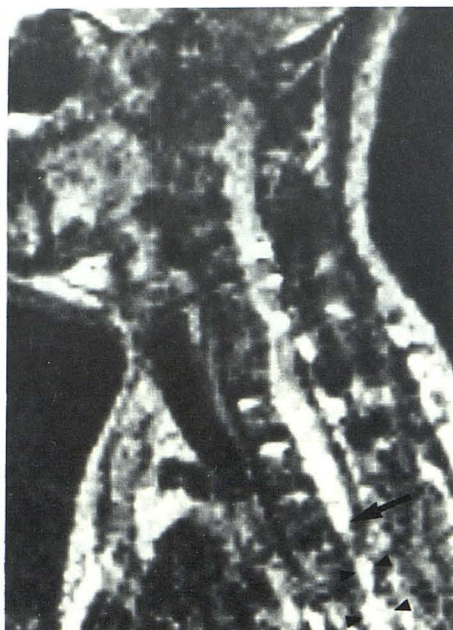
Fig. 2.—Case 2: spinal cord cyst. A, Delayed metrizamide CT shows diffuse uptake of the contrast material within the spinal cord for 5 cm above the area of original injury (C6–C7 fracture/subluxation). Because the contrast material was not dense or well-defined, the diagnosis of myelomalacia was made. With MRI, T1-weighted images show a hypointense area within the spinal cord from the medulla (arrow in B) inferiorly to T4 (arrow in C). The fracture/subluxation at C6–C7 and its effect on the spinal canal and adjacent cord are apparent. On T2-weighted images, hyperintense signals within the cord were identified from the medulla to T3 (arrow in D) corresponding to the areas of low signal intensity in B and C. Hyperintense signals within the cord below T4 (arrowheads) indicate caudal extension of the cyst. The diagnosis by MRI was a posttraumatic spinal cord cyst. Intraoperatively, transverse sonography at T2 (E) and C2 (F) confirmed the presence of an intramedullary cyst ("c" in F). Note the cord enlargement (between open arrows in E) at T2. Shunt catheter placement into the cyst at the T2 level resulted in cyst collapse from T3 to C2.



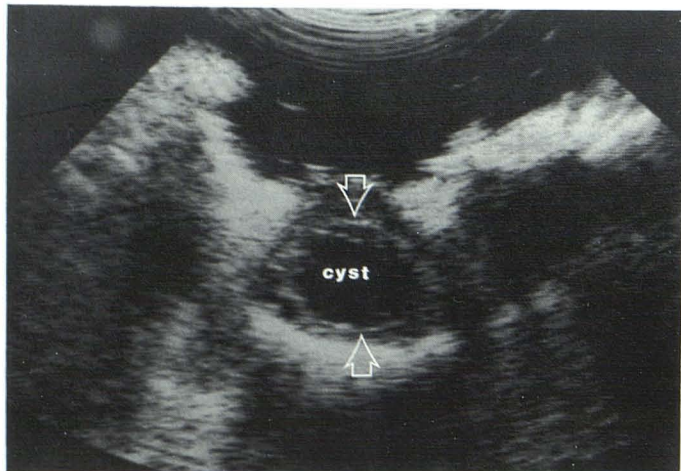
B



C



D



E



F

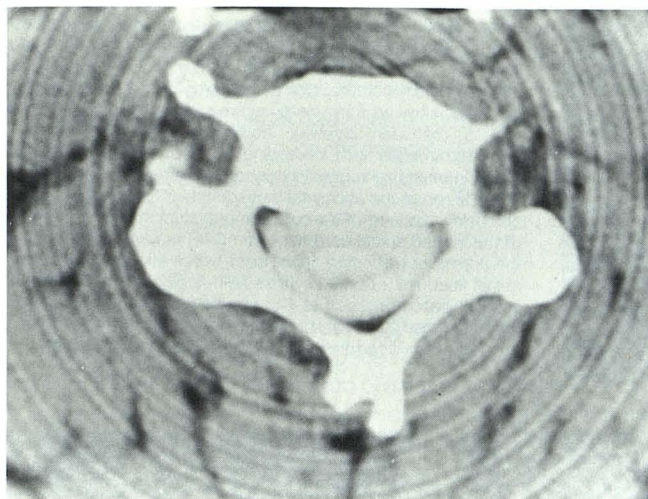
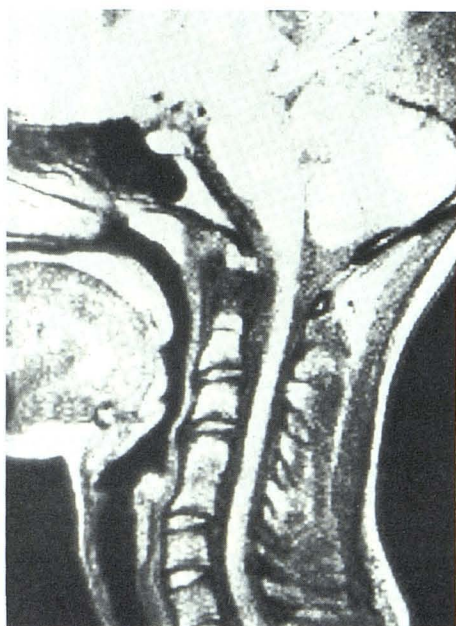
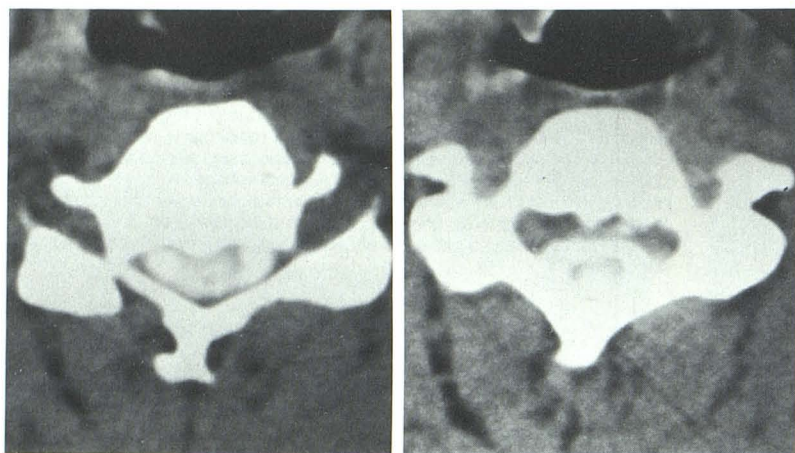
**A****B****C****D**

Fig. 3.—Case 9: myelomalacia. **A**, Delayed metrizamide CT shows dense intramedullary contrast material accumulation consistent with a posttraumatic spinal cord cyst at the C4 level. MRI shows a hypointense area (arrow in **B**) within the cord on the T1 image at the level of prior injury and prior surgery (C4–C5 intrabody fusion). However, on the T2-weighted images (**C** and **D**), the signal intensity at the C4 level was equivalent to the signal intensity from other areas of the cord that had been shown by delayed metrizamide CT and MRI to be normal. Consequently, a diagnosis of myelomalacia was made, and no surgery was performed.

Intraoperative spinal sonography was performed on the five patients who eventually had surgery (Cases 1, 2, 4, 7, and 8). Sonograms were evaluated for the presence of a number of abnormalities, such as bony or soft-tissue compression of the spinal cord or nerve roots, adhesions, extramedullary cysts, and cord pulsations; but the bulk of our attention was directed toward the appearance of the spinal cord. Specifically, we noted that an anechoic intramedullary area (e.g., Figs. 1C, 1D, 2E, and 2F) indicated the presence of a cyst, whereas a hyperechoic spinal cord (e.g., Fig. 4C) indicated myelomalacia [5]. The surgical procedure for diverting fluid from the intramedullary cyst to the adjacent subarachnoid space involved shunting the cyst via a multiple-hole ventricular shunt catheter (e.g., Fig. 1E). Fluid obtained from these cysts at the time of surgery was not subjected to laboratory analysis.

Of the 10 patients who had delayed metrizamide CT, six were diagnosed as having an intramedullary cyst, three as having myelomalacia, and one patient was diagnosed as normal. Diagnoses made by using MRI, on the other hand, showed cysts in six patients and myelomalacia in four, with agreement occurring in only five of our 10 patients (Cases 1, 4, 6, 7, and 10). In the five cases in which surgery was performed, the operative and intraoperative spinal sonography findings correlated with the MRI diagnoses in four patients (Cases 1, 2, 4, and 8) while the same findings correlated with the delayed metrizamide CT diagnoses in just two patients (Cases 1 and 4). Three patients (Cases 3, 12, and 13) had only MRI, resulting in the diagnosis of a cyst in one case and myelomalacia in two cases. We found progressive symptoms present in patients with myelomalacia (Cases 7, 11, and 12) as well as in patients with intramedullary cysts (Cases 1–6).



A

B

Fig. 4.—Case 8: myelomalacia. Delayed metrizamide CT at the level of prior C4–C5 fracture/subluxation shows a compressed spinal cord in A with intramedullary accumulation of contrast material. At the C4 level (B), 8 mm above A, the intramedullary contrast material was dense and well-defined, and a diagnosis of posttraumatic spinal cord cyst was made. The cyst extended 16 mm above and 8 mm below the level of maximum bony compression of the cord. The T1-weighted MRI image (C) showed a hypointense area within the spinal cord at C4–C5 (between arrows); however, three separate T2-weighted images with increasing TE showed no changes in signal intensity to suggest an intramedullary cyst. Specifically, at the levels of the abnormal metrizamide CTs (i.e., both above and below the level of the cord compression) the signal intensity of the injured spinal cord tissue (in D–F) was similar to that of the normal surrounding spinal cord tissue and not of cerebrospinal fluid. As a result of these MRI findings, just an anterior cervical decompression at C5 was performed. Sonography in the transverse plane (G) showed an abnormal, highly echogenic, misshaped cord (arrowheads) with no intramedullary cyst.



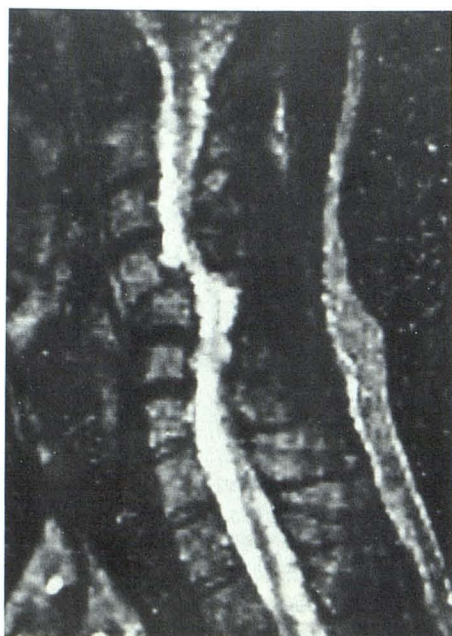
C



D



E



F



G

Three patients were diagnosed as having a cyst (Cases 3, 5, and 6) but were not operated on. Two of those (Cases 3 and 5) will have surgery only if their symptoms worsen, while the third patient (Case 6) had such a short cyst that the shunt surgery was thought to be inadvisable for the present. Cyst collapse occurred in each case following the insertion of the shunt tubing.

Discussion

The benefit of shunting posttraumatic spinal cord cysts into the adjacent subarachnoid space has been well documented [4, 5]; nonetheless, a common clinical and radiologic problem is the preoperative differentiation of myelomalacia from these intramedullary cysts. In initial experiences with delayed metrizamide CT [4], it was found that an abnormal collection of water-soluble myelographic contrast material within the spinal cord, along with a progressive neurologic dysfunction, indicated a strong probability of an intramedullary cyst. Subsequently, it was shown that in some chronically spine-injured patients, contrast material could accumulate in noncystic areas of the cord [5, 6] even if signs of progressive neurologic dysfunction were present. While the length of cord involvement may be of some help in distinguishing cyst from myelomalacia, there will be instances in which a cyst extends over a relatively short segment of the cord or in which a cord has undergone myelomalacic changes away from the site of the original bone injury. These problems point out the need for a more reliable means of diagnosing posttraumatic spinal cord cysts.

MRI, with its proven ability to detect cystic intramedullary abnormalities [7, 8], was the obvious choice for a radiologic study that could distinguish myelomalacia from cord cysts. Because intraoperative spinal sonography can readily differentiate cystic from noncystic abnormalities of the cord [5], we used that modality to compare the diagnostic accuracy of delayed metrizamide CT with MRI. Although we have studied only 13 cases to date, our results indicate that MRI is more accurate than delayed metrizamide CT in delineating the pathological changes present within a chronically injured spinal cord. Specifically, two of our patients—Case 2 (Fig. 2) and Case 5—would not have been operated on had only delayed metrizamide CT been available, because that study suggested only myelomalacia. Both these patients, however, did have MRI, which showed cysts, a circumstance that was confirmed at surgery with intraoperative ultrasound. Conversely, two patients—Case 8 (Fig. 4) and Case 9—whose delayed metrizamide CT findings strongly suggested a cyst, showed changes most consistent with myelomalacia on MRI. Since one of those patients (Case 8) had an anterior cervical decompression, we were able to perform intraoperative spinal sonography through the corpectomy defect and prove the lack of intramedullary cyst. It appears, therefore, that delayed metrizamide CT is useful for pointing out an abnormality within the cord, but it cannot reveal exactly what that abnormality is. Thus, in our institution, shunting spinal cord cysts is now done only when the MRI is positive for that diagnosis.

We believe that the difference in relaxation times between

normal spinal cord tissue, myelomalacia, and intramedullary cysts is the factor that allows MRI to be more accurate than delayed metrizamide CT in portraying the pathologic changes present in an injured cord. The intramedullary microcystic and gliotic changes present in an myelomalacic cord [9] contribute to prolongation of the T1 relaxation time. The result of these changes on T1-weighted images is a low-intensity signal that mimics cerebrospinal fluid (e.g., Fig. 3B). The normal surrounding spinal cord has a more intense signal because of its shorter T1 relaxation time. On the T2-weighted images, areas of myelomalacia on the early echoes have signal intensities that resemble a normal spinal cord (e.g., Fig. 3C). As signals are obtained at increasingly long echo times (more heavily T2-weighted), the effect of the long T2 relaxation time of cerebrospinal fluid and equivalent fluid becomes evident. Specifically, the cerebrospinal fluid becomes hyperintense compared with both the normal spinal cord and the myelomalacia (Fig. 2D), since both have a shorter T2 relaxation time than cerebrospinal fluid. These factors help explain the difference in appearance between myelomalacia, spinal cord cysts, and normal cord tissue. The imaging situation in some cases, however, may not be as clearly defined as it would seem from this description, because posttraumatic spinal cord cysts develop in areas of previously damaged spinal cord tissue, resulting in a rim of myelomalacia tissue adjacent to a cord cyst. As more cases are analyzed with higher-resolution MRI, it may be possible to detect small areas of myelomalacia in proximity to the larger cysts. From a practical standpoint, however, this may have little or no surgical significance, because in patients with new or progressive symptoms the concern is the cephalad extension of a cyst beyond the area of myelomalacia into areas of the spinal cord that previously had been normal. What is occurring within the cord at the exact level of prior cord injury is of little importance in these patients compared with the dynamic changes occurring above the injury site.

The cerebrospinal fluid equivalency of the cyst fluid is consistent with the postulated mechanism for the formation of posttraumatic spinal cord cysts [4] and explains the MRI signals obtained from these intramedullary cysts. Although we did not perform a chemical analysis of the cyst fluid, the gross appearance of the fluid was identical to cerebrospinal fluid. We recognize the possibility that some of these types of cysts may have an increased protein content [6], resulting in a shortened T1 and T2, and thus altering the MRI appearance from what we have observed so far. In future cases, we plan to correlate the MRI appearance of these cysts with possible abnormalities in protein content.

We believe that MRI is the most efficient and effective preoperative procedure for determining the presence of a cord cyst. In institutions where MRI is not available, referral to an MRI facility should be considered when the delayed metrizamide CT is positive for intramedullary contrast material accumulation. On the basis of our experience over the past five years with more than 50 chronically injured spinal cord patients, we consider the possibility of the existence of a sizable (i.e., shuntable) intramedullary cyst in the face of a negative delayed metrizamide CT to be extremely remote. In

this study, we encountered only one patient (Case 11) in whom the delayed metrizamide CT was normal but the MRI was positive; and in that patient only myelomalacia, not a cyst, was identified.

In summary, our results indicate that in patients with progressive neurologic symptoms who have sustained prior severe cervical spinal cord injury, MRI is the only preoperative study needed to distinguish myelomalacia from a posttraumatic spinal cord cyst. We found that when T1-weighted SE images showed areas of hypointensity, a cord cyst could be distinguished from myelomalacia on the T2-weighted images. A posttraumatic spinal cord cyst will be hypointense relative to the spinal cord on moderately T2-weighted images and hyperintense on the more heavily T2-weighted images. Myelomalacia, on the other hand, will be relatively isointense to the normal spinal cord on the moderately T2-weighted images. The above criteria probably can also be applied to the evaluation of the thoracic cord when better-quality images are available, either through improvements in the body radio-frequency coil or with the development of surface coils.

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