Intraoperative Spinal Sonography of Soft-Tissue Masses of the Spinal Cord and Spinal Canal

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Intraoperative spinal sonography (IOSS) was used to evaluate and monitor the progress of surgery in 18 patients with soft-tissue masses of the spinal canal and spinal cord. With intramedullary masses, IOSS showed not only the site of maximum cord enlargement so that a precise biopsy could be performed but also was able to demonstrate the zone of transition between the mass and normal cord tissue. With extradural masses and intradural extramedullary masses, IOSS showed the exact size and location of the masses and confirmed their removal and/or adequate spinal cord decompression. IOSS indicated the extent of bone removal necessary to give adequate exposure to accomplish total removal of these masses or to localize the proper level for tissue biopsy. IOSS also indicated the need to open the dura when there had been unsuspected transdural tumor spread or when bony decompression had not been sufficient to relieve the pressure on the spinal cord in tonsillar ectopia. Intraoperative spinal sonography is recommended in all cases of spinal surgery performed to resect or biopsy soft-tissue masses of the spinal canal or spinal cord.

A significant advance in spinal surgery has been made possible by the recent use of real-time sonography in the operating room, a technique we have termed *intraoperative spinal sonography* (IOSS). Despite this, only four reports of its use have appeared. The intraoperative sonographic appearances of six intradural extramedullary masses [1–3] and three intramedullary cysts [3] have been shown recently. In patients with prior spinal cord trauma, we have demonstrated the use of IOSS in the assessment and surgical decompression of posttraumatic spinal cord cysts [4]. Until now no published articles have dealt with IOSS in a wide range of tumors and inflammatory masses of the spinal canal and spinal cord. Over the past 19 months we performed IOSS on 18 patients with soft-tissue masses of the spinal canal or spinal cord. Our objective is to illustrate the sonographic appearance of various types of spinal masses and to show the specific benefits of IOSS in spinal surgery.

Subjects and Methods

All 18 patients were examined with the ATL NeuroSectOR or the ATL Mark 3001 portable real-time unit (Advanced Technology Laboratories, Bellevue, WA) with a 7.5 MHz in-line transducer. The transducer was coupled to a surrounding sterile latex sheath via a sterile gel, and care was taken to remove all air bubbles that may have become trapped between the transducer and the sheath. Rubber bands were placed over the latex sheath to secure it to the transducer.

The sonographic examination was performed either from a posterior approach after a laminectomy or from an anterior approach after complete or partial removal of a vertebral body (corpectomy). The transducer element is 6.4 mm and small enough to fit into the surgical fields, and it was placed in a fluid bath (either Ringer solution or sterile saline) 3–4 cm from the dura, the optimal focal zone for this sized transducer. The examination was performed in the transverse and longitudinal planes, with care taken to move the transducer over the entire

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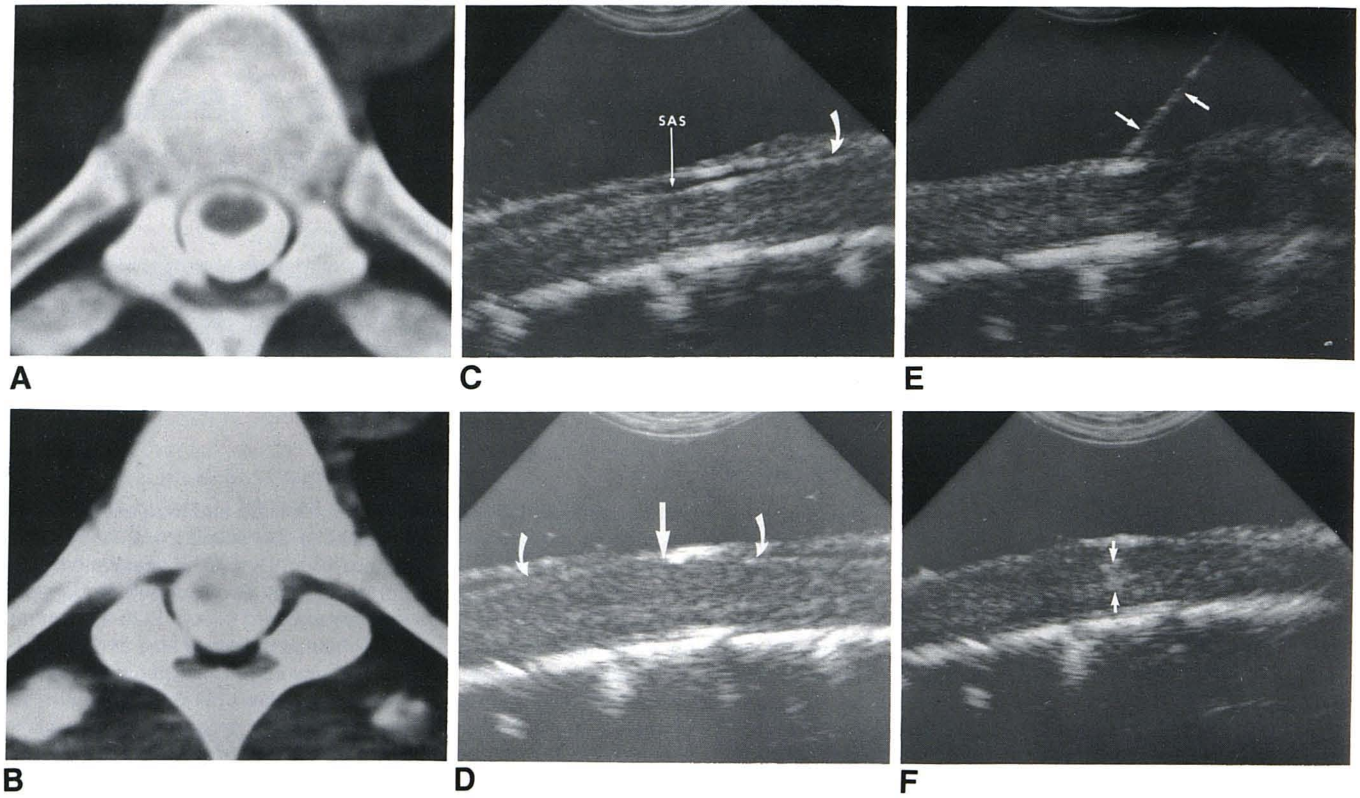

Fig. 1.—Progressive spastic paraparesis. Myelogram was normal, but, because of high degree of clinical suspicion of thoracic cord mass, immediate and 4 hr delayed water-soluble contrast (metrizamide) CT was performed. **A**, Immediate metrizamide scan. No evidence of cord enlargement. **B**, Delayed scan at same level (T5). Diffuse infiltration of metrizamide into cord substance. On the basis of delayed metrizamide CT, a process that had changed the permeability of the spinal cord was suspected, e.g., myelitis, infarction, or tumor. Because of the patient's progressive neurologic deterioration, infiltrating neoplasm was believed most likely, even though there was no radiologic evidence of cord enlargement. Surgery was recommended, and a T4–T5 laminectomy was performed. **C**, Initial IOSS. Normal subarachnoid space (SAS) and normal-sized cord in center of field. At caudal end of operative site, cord began to enlarge and subarachnoid space narrowed (*arrow*). Laminectomy was extended one segment more inferiorly. **D**, Repeat IOSS showed enlarged cord (*between curved arrows*) and obliterated dorsal subarachnoid space at point of maximum cord widening (*straight arrow*). Swollen cord was not obvious to the surgeon. A well defined central echo was not seen, which also suggested an abnormal spinal cord. The dura was subsequently opened, and a metallic probe (**E**, *arrows*) was placed over point of cord enlargement to localize area where biopsy would best be performed. **F**, Postbiopsy IOSS showed an echogenic area in cord (*arrows*), most consistent with small amount of intramedullary blood. In addition to the value of IOSS, this case points out the need to perform delayed metrizamide CT even in the face of normal myelography when there is a strong clinical indication of spinal cord abnormality. Pathologic diagnosis was low-grade glioma.

length and width of the operative field. Both static and videotaped images were obtained. Our convention is to label the transverse sonograms just as the surgeon sees the operative field, so that the patient's left is on the viewer's left after a laminectomy and the patient's right is on the viewer's left after a corpectomy. On longitudinal sonograms cephalad is to the viewer's left.

Typically the first IOSS study is performed after bone removal (either laminectomy or corpectomy) but before any other surgical manipulation. We have termed this stage *initial IOSS*, and it serves as a baseline for comparison with other images obtained during surgery. As the operation proceeds, the progress of the surgery is monitored with IOSS. This stage may indicate the need for additional bone resection to widen the surgical field or may demonstrate the presence of unsuspected residual tumor tissue. *Final IOSS* serves to confirm adequate tumor removal and spinal cord or cauda equina decompression before closure of the wound.

Results

Table 1 lists the types and numbers of soft-tissue masses that we examined with IOSS. As a result of our experience

TABLE 1: **Soft-Tissue Masses Examined with Intraoperative Spinal Sonography**

Type	No. Cases
Intramedullary:	
Astrocytoma	1
Ependymoma	1
Metastasis	1
Myelitis	1
Dermoid	1
Subtotal	5
Intradural, extramedullary:	
Meningioma	3
Neurofibroma	2
Metastasis	1
Tonsillar ectopia (Chiari I malformation)	1
Lipoma	1
Subtotal	8
Extradural:	
Metastasis	3
Abscess	2
Subtotal	5
Total	18

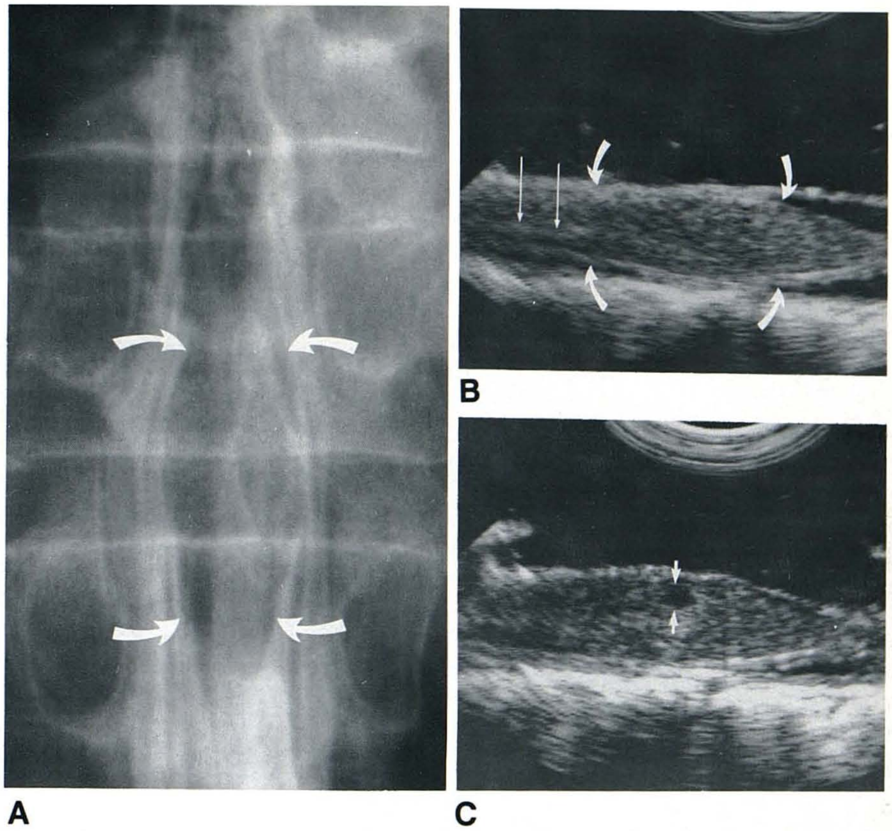

Fig. 2.—Patient with lung carcinoma but no known metastasis developed urinary incontinence. **A**, Water-soluble-contrast myelograpy showed enlarged conus (*curved arrows*). T12–L1 laminectomy was performed. **B**, Initial IOSS identifies widened conus (*curved arrows*). Central echo (*straight arrows*) was seen down to level where conus began to enlarge, suggesting zone of transition between normal spinal cord tissue and cord neoplasm at point where visualization of central echo stopped and cord widened. In this, as in all IOSS images, structures at periphery of sonographic field (e.g., central canal in this case) are not defined as sharply as structures along central acoustical axis, because peripheral structures tend not to be perpendicular to sound beam. As in fig. 1E, dura was opened and metallic probe was used to identify exact point where biopsy would best be performed. **C**, Final IOSS after biopsy shows small cystic lesion (*arrows*) corresponding to area in cord from which tissue was taken. Pathologic diagnosis was metastatic lung carcinoma.

we have identified four distinct benefits afforded by IOSS in the surgery of soft-tissue masses of the spinal cord and spinal canal:

Identifies Area of Maximum Cord Enlargement so that Precisely Located Biopsy Can Be Performed or Shows the Necessity of Extending Laminectomy

Figures 1A and 1B show immediate and 4 hr delayed metrizamide computed tomography (CT) in a patient with progressive spastic paraparesis. An infiltrating intramedullary mass that was not causing cord enlargement was suspected at the T5 level. At surgery after a laminectomy there was no visual appearance of cord tumor; however, initial IOSS (fig. 1C) showed that at the caudal end of the operative field the spinal cord was beginning to enlarge. This persuaded the surgeon to lengthen his operative field inferiorly by removing more bone. After this IOSS clearly localized the area of cord enlargement (fig. 1D). The dura was opened at this level, and a metallic probe was placed over the cord (fig. 1E) so that a biopsy could be performed at precisely the proper location. Postbiopsy blood within the cord substance was seen on the final IOSS (fig. 1F).

In figure 2B, the proper level for a biopsy of a conus mass was identified with IOSS. A postbiopsy defect within the cord (fig. 2C) indicated the location from which tissue was taken.

Demonstrates Zone of Transition between Intramedullary Mass and Normal-Appearing Cord Tissue

In figure 2B the loss of reflectivity of the central echo occurred at the level where the cord began to enlarge, indicating the probable zone between the conus mass (a metastasis) and grossly normal spinal cord tissue.

Figures 3E and 3F showed a more definite demarcation between a benign lesion and normal cord tissue. Here the surface of an encapsulated dermoid tumor could be separated from the noninvolved spinal cord.

Outlines Size and Location of Extramedullary Masses and Confirms Tumor Removal and Adequate Cord or Cauda Equina Decompression

Figure 4 shows spinal cord compression by an extramedullary mass (metastatic carcinoid of the lung) and the subsequent decompression of the cord on the final IOSS after the tumor had been removed.

In figure 5, an anterior surgical approach was used to decompress the spinal canal. Because of that, tumor tissue was removed at the time of vertebral body resection, and initial IOSS therefore showed no compression on the spinal canal contents (figs. 5B and 5C) and indicated that no further surgical manipulation was required.

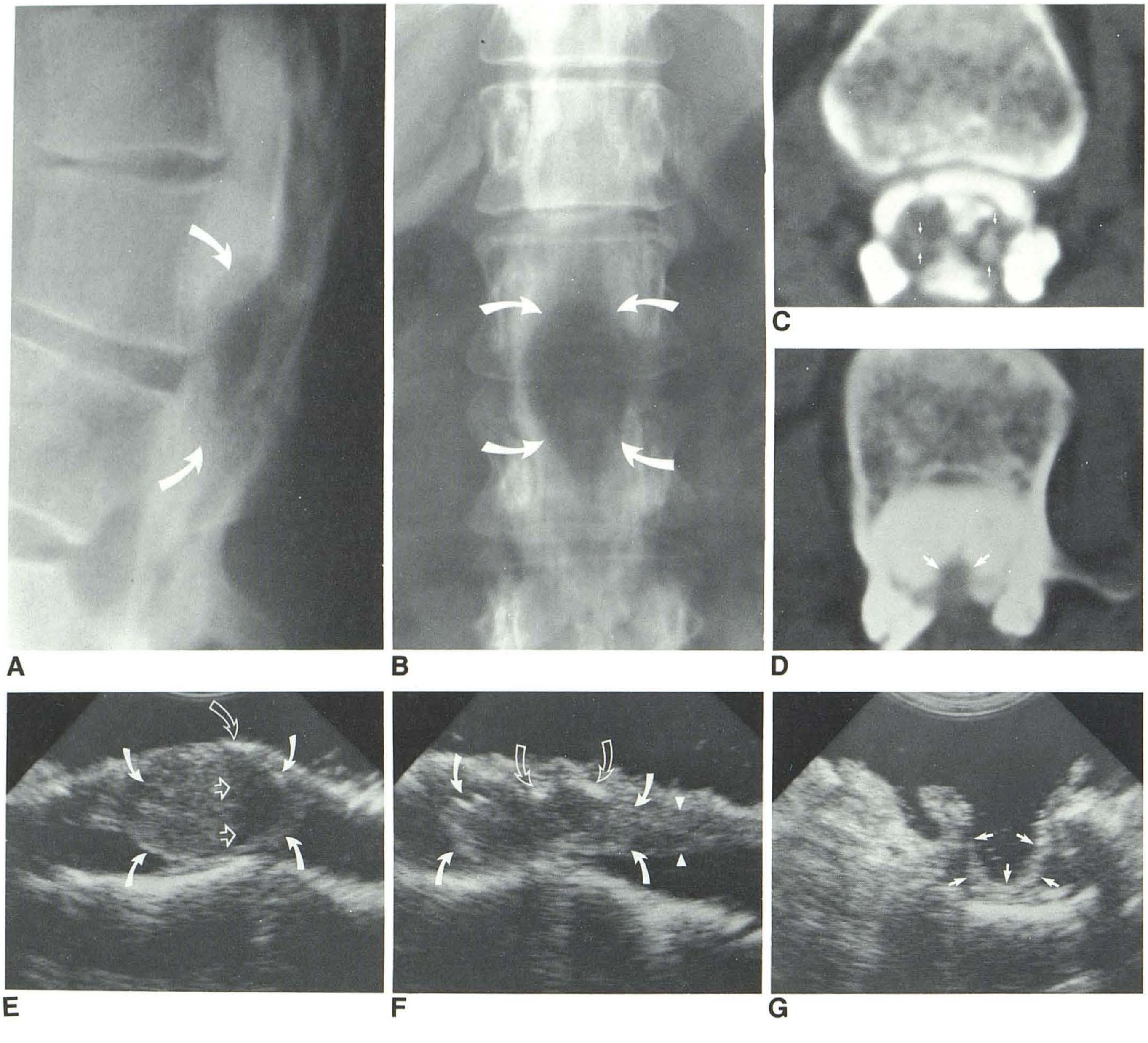

Fig. 3.—36-year-old patient had three previous operations (19, 9, and 5 years ago) for attempted removal of dermoid tumor of lower thoracic cord. Because of increasing incontinence and paraplegia water-soluble-contrast myelography (**A** and **B**) and metrizamide CT (**C** and **D**) were performed. **A** and **B**, At L1–L2, radiopaque contrast caps a mass (*arrows*) at level of conus medullaris. **C**, Metrizamide CT at L1–L2 level shows irregular mass within which there were areas of increased density (*arrows*). We were uncertain whether increased densities represent calcium or metrizamide that had penetrated into interstices of tumor. **D**, 1 cm below **C** at mid L2 level. Normal-appearing tip of conus (*arrows*). On these studies it was difficult to determine anatomic plane that separated tumor from normal spinal cord tissue. **E**, Initial longitudinal IOSS to right of midline. A well circumscribed mass (*solid curved arrows*) corresponded to oval mass in right side of canal in **C**. Bright reflecting echo on dorsal surface of mass (*open curved arrow*) with acoustical shadowing (*open straight arrows*) ventral to it represented calcium on surface of tumor. **F**, Initial longitudinal IOSS to left of midline shows less bulky mass (*solid curved arrows*) than was seen on right side of canal. Normal-sized conus (*arrowheads*) below mass corresponds to normal distal conus seen on **D**. On basis of these sonograms zone of transition between normal spinal cord and dermoid tumor was established. **F** shows additional areas of calcification (*open curved arrows*) within tumor. **G**, Final IOSS in transverse plane at L1 after removal of dermoid tumor shows rim of echogenic tissue (*arrows*), which was combined capsule of tumor that remained after tumor had been shelled out of spinal cord and small amount of residual spinal cord tissue. It was decided not to dissect capsule away from this residual cord tissue because of fear of causing irreversible neurologic damage. Pathologic diagnosis was dermoid tumor.

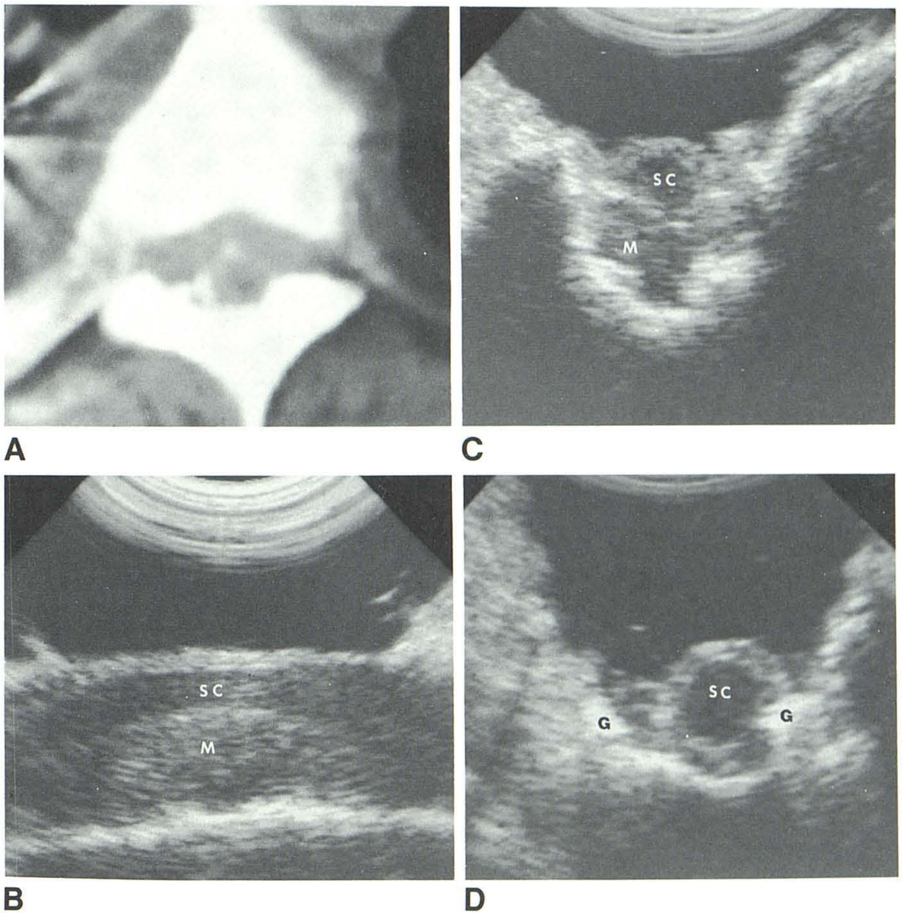

Fig. 4.—Patient with carcinoid of lung that had metastasized to T5. **A**, Water-soluble-contrast CT shows soft-tissue mass within spinal canal displacing cord posteriorly. T4–T5 laminectomy was performed. **B** and **C**, Initial IOSS showed that mass (M) was more echogenic than spinal cord (SC) and was compressing and displacing spinal cord posteriorly. Area of maximum cord compression is ventral and to left of midline. **D**, After tumor removal and cord decompression, final IOSS shows no residual tumor and spinal cord has assumed a more rounded configuration and is no longer being displaced or compressed on its ventral surface. Highly reflective areas on both sides of spinal cord are Gelfoam powder (G). Pathologic diagnosis was metastatic carcinoid from the lung.

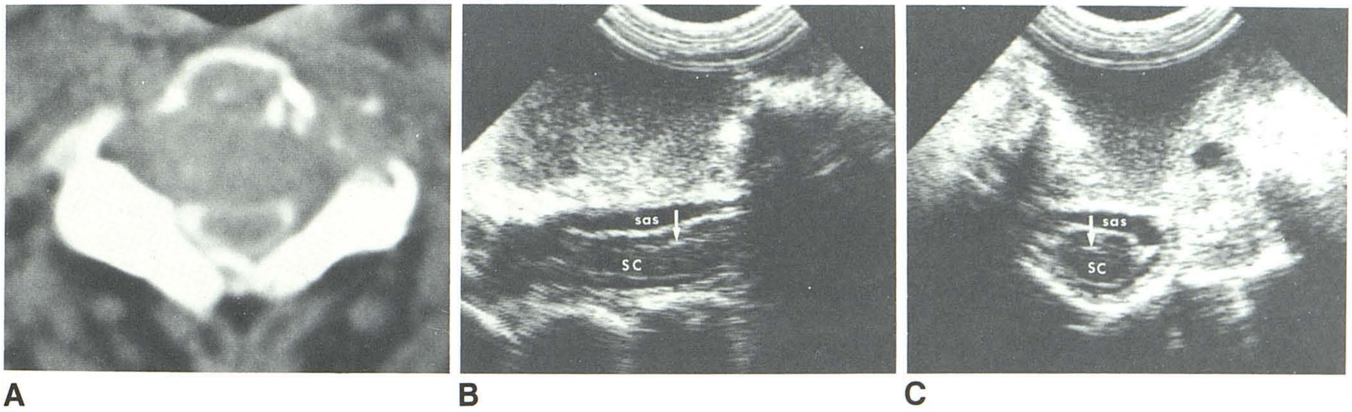

Fig. 5.—Bone destruction involving C3 vertebral body with contiguous soft-tissue tumor compressing ventral subarachnoid space and spinal cord was seen on water-soluble-contrast myelography with CT. Because of location of this mass, anterior surgical approach was used in which there was resection of C3 vertebral body (i.e., corpectomy) and removal of bulk of adjacent soft-tissue mass. **B** and **C**, Initial IOSS after surgery. Blood was present in corpectomy defect, accounting for highly reflective echoes within fluid bath. There is no compression of spinal cord (SC), and ventral subarachnoid space (SAS) is normal in size. There is visualization of central echo (*arrows*) on both longitudinal and transverse IOSS (cf. fig. 6D). IOSS indicated that adequate decompression of spinal cord had been performed and no further surgery was necessary. Pathologic diagnosis was metastatic breast carcinoma.

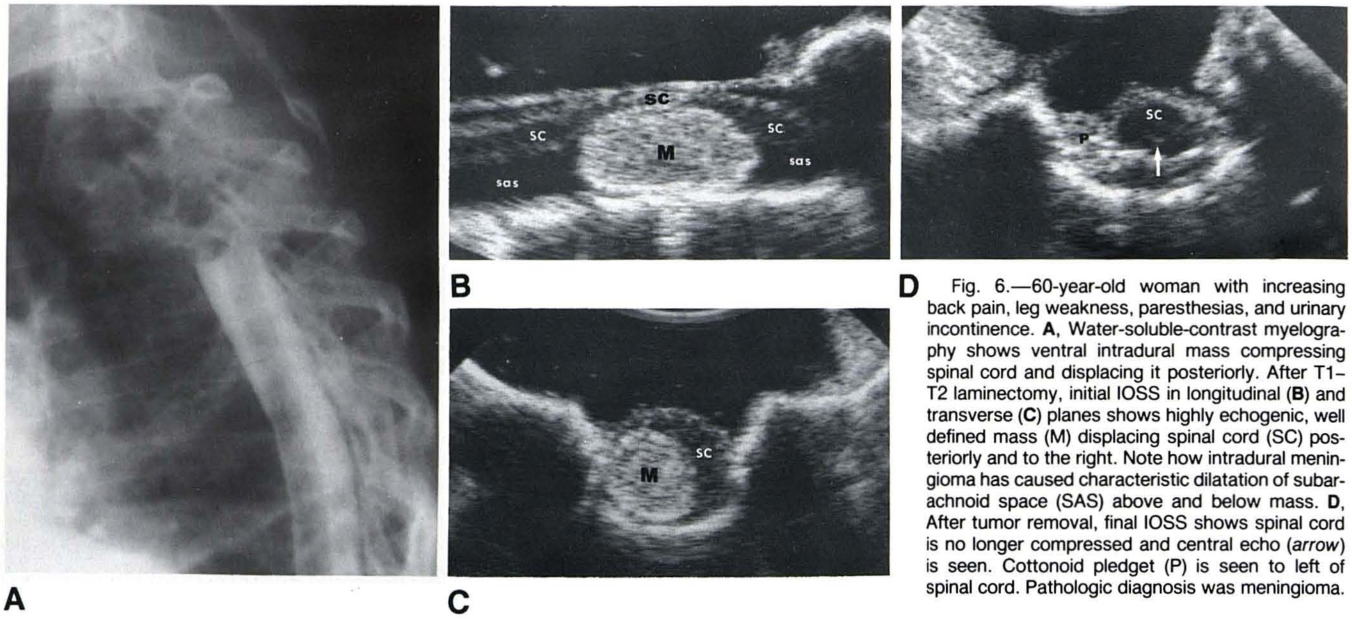

Fig. 6.—60-year-old woman with increasing back pain, leg weakness, paresthesias, and urinary incontinence. **A**, Water-soluble-contrast myelography shows ventral intradural mass compressing spinal cord and displacing it posteriorly. After T1–T2 laminectomy, initial IOSS in longitudinal (**B**) and transverse (**C**) planes shows highly echogenic, well defined mass (M) displacing spinal cord (SC) posteriorly and to the right. Note how intradural meningioma has caused characteristic dilatation of subarachnoid space (SAS) above and below mass. **D**, After tumor removal, final IOSS shows spinal cord is no longer compressed and central echo (*arrow*) is seen. Cottonoid pledget (P) is seen to left of spinal cord. Pathologic diagnosis was meningioma.

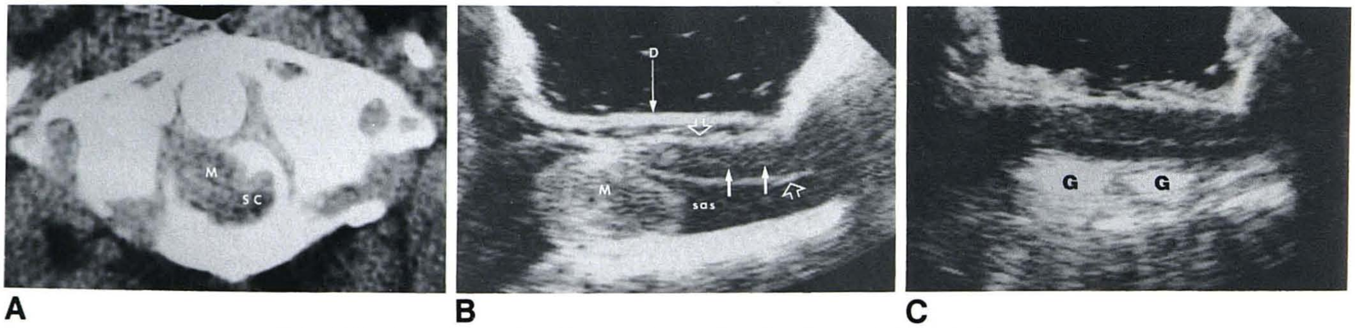

Fig. 7.—**A**, Myelography with CT at C1 level in patient with weakness and numbness of arms and legs shows ventral intradural mass (M) compressing spinal cord (SC) and displacing it posteriorly and to the left. **B**, After C1–C2 laminectomy initial longitudinal IOSS shows echogenic mass (M) with surface sharply outlined by surrounding cerebrospinal fluid within subarachnoid space (SAS). Spinal cord is markedly compressed at level of mass, but caudad to mass cord surfaces show normal high reflectivity (*open arrows*) and central echo (*closed arrows*). Beneath dura-arachnoid layer (D) some cerebrospinal fluid was seen within dorsal subarachnoid space. Upper end of mass was at level of foramen magnum and it extended inferiorly to C2 level. **C**, After opening dura and removing mass, final IOSS showed decompressed cord. Gelfoam (G) packing was seen in surgical bed from where tumor had been removed. Pathologic diagnosis was meningioma.

Figures 6 and 7 show that intradural extramedullary masses are well demarcated. Complete tumor resection and cord decompression was shown on the final IOSS.

Indicates Need to Open Dura where Tumor Has Unexpectedly Extended through Dura or where Bony Decompression Has Not Helped Relieve Pressure on Spinal Cord in Tonsillar Ectopia

In figure 8, total removal of an extradural mass was achieved. However, at completion of that surgery, IOSS showed there had been unsuspected transdural spread of the mass, a fact which mandated the opening of the dura to remove this intradural component. Final IOSS showed no residual tumor.

Figure 9 shows that the bony decompression at the craniovertebral level was insufficient to relieve the pressure on the upper cervical cord caused by tonsillar ectopia (Chiari I malformation). Because of that finding, a freeze-dried dural graft was applied to create a larger space for the cord and the abnormally low-lying tonsils.

Discussion

Soft-tissue masses in the spinal cord or within the spinal canal are operated on either to totally remove the mass, to obtain a biopsy for tissue diagnosis, or to effect a partial decompression of the spinal cord or cauda equina. During these operative procedures it is often difficult for the surgeon to visualize the mass or to assess the progress of surgery,

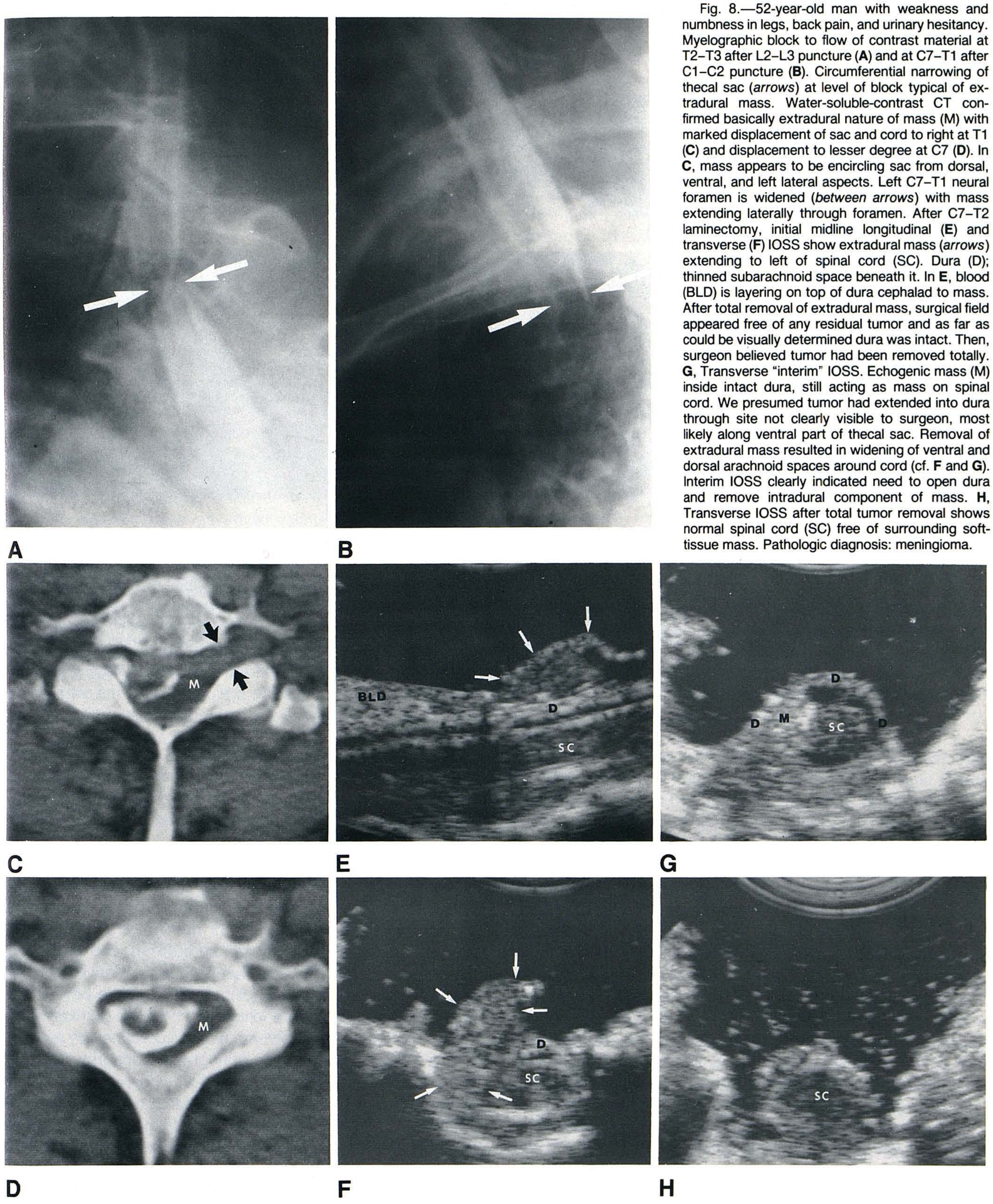

Fig. 8.—52-year-old man with weakness and numbness in legs, back pain, and urinary hesitancy. Myelographic block to flow of contrast material at T2–T3 after L2–L3 puncture (**A**) and at C7–T1 after C1–C2 puncture (**B**). Circumferential narrowing of thecal sac (*arrows*) at level of block typical of extradural mass. Water-soluble-contrast CT confirmed basically extradural nature of mass (M) with marked displacement of sac and cord to right at T1 (**C**) and displacement to lesser degree at C7 (**D**). In **C**, mass appears to be encircling sac from dorsal, ventral, and left lateral aspects. Left C7–T1 neural foramen is widened (*between arrows*) with mass extending laterally through foramen. After C7–T2 laminectomy, initial midline longitudinal (**E**) and transverse (**F**) IOSS show extradural mass (*arrows*) extending to left of spinal cord (SC). Dura (D); thinned subarachnoid space beneath it. In **E**, blood (BLD) is layering on top of dura cephalad to mass. After total removal of extradural mass, surgical field appeared free of any residual tumor and as far as could be visually determined dura was intact. Then, surgeon believed tumor had been removed totally. **G**, Transverse "interim" IOSS. Echogenic mass (M) inside intact dura, still acting as mass on spinal cord. We presumed tumor had extended into dura through site not clearly visible to surgeon, most likely along ventral part of thecal sac. Removal of extradural mass resulted in widening of ventral and dorsal arachnoid spaces around cord (cf. **F** and **G**). Interim IOSS clearly indicated need to open dura and remove intradural component of mass. **H**, Transverse IOSS after total tumor removal shows normal spinal cord (SC) free of surrounding soft-tissue mass. Pathologic diagnosis: meningioma.

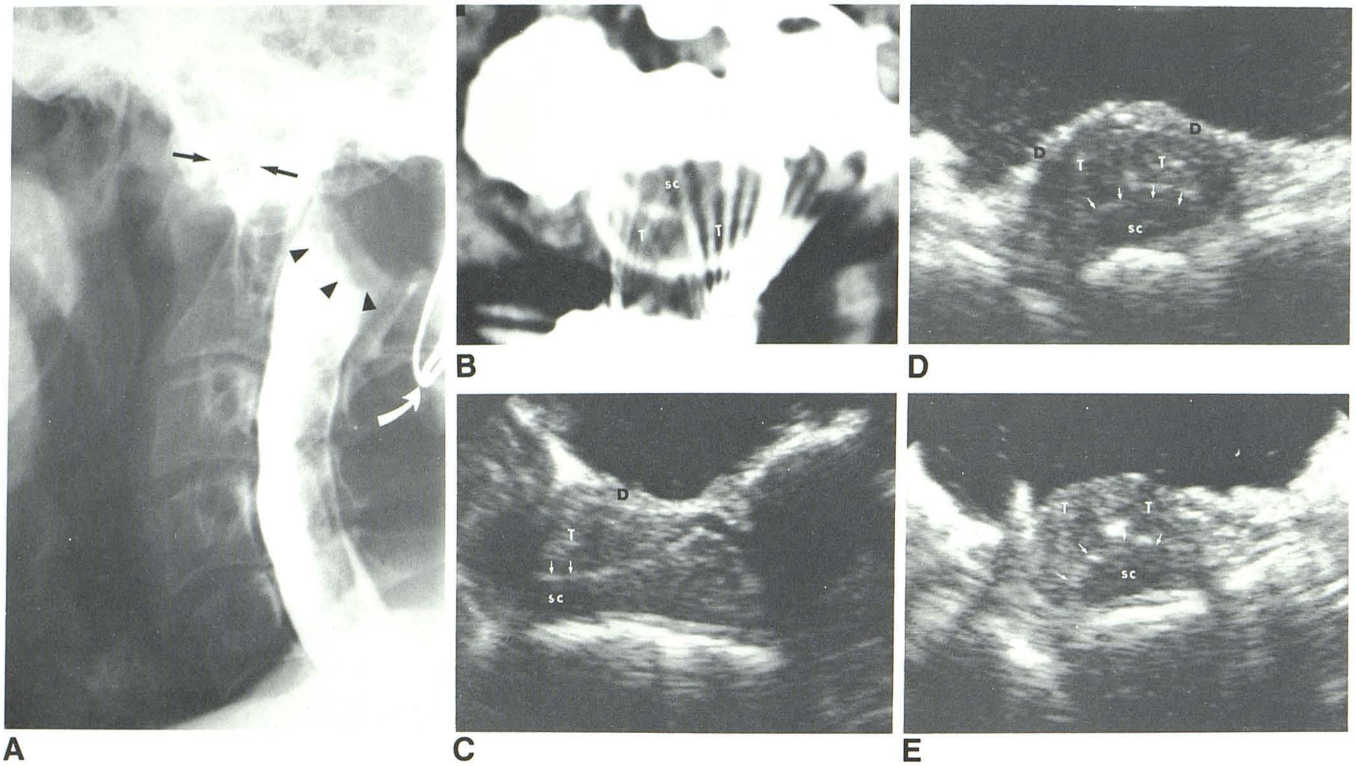

Fig. 9.—Posterior wire fusion was performed at another hospital for atlantoaxial subluxation in patient who was thought to have rheumatoid arthritis. Postoperatively, increased quadriparesis, dysphagia, urinary hesitancy, and nystagmus prompted reevaluation. **A**, Water-soluble-contrast myelography shows atlantoaxial subluxation (*black arrows*), lower half of posterior wire fusion (*curved arrow*), and mass (*arrowheads*) in spinal canal at C1. **B**, Contrast CT image is degraded because of streaking from wires; however an intradural mass diagnosed as cerebellar tonsils (T) is seen in posterior part of canal and displacing spinal cord (SC) anteriorly. Posterior fusion was removed, but despite this decompression initial longitudinal (**C**) and transverse (**D**) IOSS showed anterior displacement of spinal cord and flattening of its dorsal surface (*arrows*) by low-lying cerebellar tonsils, confined posteriorly by intact dura-arachnoid layer (D). Cord compression demonstrated with IOSS indicated need to open dura and apply freeze-dried dural graft to give cord and tonsils more room within canal. **E**, After opening dura, transverse IOSS shows less mass effect on dorsal surface of spinal cord (*arrows*) than was seen before opening dura (cf. **D**). Diagnosis was Chiari I malformation associated with atlantooccipital fusion and atlantoaxial subluxation.

particularly when the mass is within the spinal cord or when, after a laminectomy, the mass is ventral in location. IOSS is a technique that allows the surgeon and radiologist to overcome many of these problems by virtue of its ability to image the entire spinal canal and its contents during surgery.

Our experience (table 1) with soft-tissue masses of the spinal canal and cord has shown IOSS to be particularly valuable in a number of circumstances. In intramedullary tumors, IOSS can identify the level of maximum cord enlargement (figs. 1 and 2), which is particularly important when there is little evidence visually of a swollen cord at surgery. A single microsurgical biopsy at the site identified by IOSS may be sufficient to establish a tissue diagnosis and obviate multiple violations of the spinal cord tissue. Limiting the area of spinal cord parenchymal disruption is clearly important to decrease the potential neurologic complications of a spinal cord biopsy.

Identifying the interface between normal spinal cord tissue and an intramedullary mass (figs. 2 and 3) is important if an attempt to remove the tumor is to be made. We have found that the normal spinal cord is composed of low-level echoes, it has highly reflective surfaces, and within the cord is a linear central echo [5]. When these features are lost, that is, when there is slightly increased echogenicity of the cord, when there is a totally anechoic area within the cord, when the central echo is lost, or when the highly reflective surfaces of the cord are no longer seen, an intramedullary process is suspected. These sonographic abnormalities are not specific for intramedullary tumors, since some of the same changes have been seen in injured spinal cords [4]; however, any one or a combination of these findings may indicate a zone of transition between normal and abnormal spinal cord tissue. In cases in which complete tumor removal is contemplated, the desired limits of surgery can be outlined, and as a result this technique may reduce the chances of leaving unsuspected tumor behind or removing normal tissue beyond the confines of the tumor. In addition, the chances of missing the proper level of tumor involvement of the cord may be reduced with IOSS. If no or minimal sonographic abnormalities (fig. 1C) are seen at the level of operation, widening of the laminectomy by a segment either inferiorly or superiorly may uncover a mass (fig. 1D), which might have otherwise gone undiscovered. The result of spinal cord biopsy, either a small hematoma at the site of biopsy (fig. 1F) or a small fluid collection within the biopsy bed (fig. 2C), can also be seen with IOSS.

With extramedullary masses, the ability of the surgeon to image the entire mass depends to a great extent on the approach. If a laminectomy is performed, ventrally located masses (figs. 4, 6, and 7) may be partly or totally hidden by the spinal cord or thecal sac. In those cases, IOSS can immediately show the exact location and size of the mass, without having to retract the cord or thecal sac or without having to perform more bone or soft-tissue resection. This allows for a more direct approach to the mass and may facilitate more rapid tumor resection. The results of complete or subtotal tumor removal and cord decompression can then be assessed with repeat IOSS (figs. 3, 4, and 6–8). We have imaged the central echo after cord decompression in a number of cases (figs. 5 and 6).

If an anterior approach (i.e., partial or total removal of a vertebral body) is used (fig. 5), the bony surgical defect may be small so that it is frequently difficult for the surgeon to assess the results of his anterior decompression. Under most circumstances, however, this defect is usually large enough to allow introduction of the transducer tip into the area of bone resection. In those cases IOSS can give an immediate assessment of the effect of the removal of the bone and associated soft-tissue mass (figs. 5B and 5C).

Masses may appear to be located in the extradural space on preoperative radiographic studies and on surgical inspection after a laminectomy; however, they may be shown by IOSS to actually have an intradural component (fig. 8G). Without IOSS, this type of tumor extension may not be appreciated and consequently may be inadequately or subtotally removed. The importance of removing an entire tumor, both its extradural and intradural components, is obvious, but under some circumstances it may not be possible to recognize this type of transducer tumor extension without IOSS.

Similarly IOSS may show that bony decompression alone is not sufficient to relieve the pressure on the upper cervical spinal cord in cases of tonsillar ectopia (figs. 9C and 9D) and consequently may indicate the need to open the dura and apply a dural graft as a further measure to relieve the mass effect on the spinal cord. Without IOSS, the surgery as shown in figure 9 may have ended after the bone resection, and therefore decompression of the spinal canal contents may never have been achieved.

All the extramedullary masses we have studied with IOSS are of high ecogenicity (figs. 4 and 6–8) and thus are easily separable from the normal hypoechoic spinal cord. However, we have been unable to distinguish the various types of extramedullary masses by their sonographic patterns. On the other hand, the intramedullary masses (figs. 1–3) we have studied so far have shown only a slight difference in echogenicity from that of normal cord tissue. In those cases the other sonographic criteria we have discussed above are helpful in diagnosis.

On the basis of our experience we believe that IOSS is invaluable in the surgery of soft-tissue masses of the spinal cord and spinal canal. We recommend its use in those cases where tumor biopsy or resection is planned.

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