AJNR

Intraoperative sonography of cervical spinal cord injury: results in 30 patients.

S E Mirvis and F H Geisler

AJNR Am J Neuroradiol 1990, 11 (4) 755-761
http://www.ajnr.org/content/11/4/755

Intraoperative Sonography of Cervical Spinal Cord Injury:
Results in 30 Patients

Stuart E. Mirvis[1,2]
Fred H. Geisler[1,3,4]

Intraoperative spinal sonography (IOSS) with a 7.5-MHz sector transducer was performed in 30 patients with cervical spine injury associated with neurologic deficits. A laminectomy (25 patients) or anterior corpectomy (five patients) during spinal surgery provided the IOSS imaging window. The surgery was performed for either spinal decompression or fixation as part of the initial care of these patients and occurred 1 to 39 days (mean, 12.4 days) after injury. Parenchymal spinal cord lesions at the level of cervical fracture or stenosis that were compatible with the initial neurologic deficits were detected by IOSS in 28 (96.5%) of 29 patients with technically adequate studies. Lesions appeared as foci of increased echogenicity and were sorted into five injury grades (0 through IV). The IOSS injury grade in each patient was determined by the maximal diameter of regions of increased echogenicity and/or cyst formation in either the sagittal or transverse image plane. The extent of initial neurologic injury and its recovery was assessed by using the ASIA motor score (0 to 100 unit scale) at admission and during follow-up. The IOSS injury grade was correlated with the initial ASIA motor score ($p < 0.009$, Spearman's Rank Order Test), indicating that the IOSS echogenicity is related to the extent of initial clinical motor deficit. Regression analysis disclosed that both the IOSS injury grade and the initial ASIA score were correlated with the follow-up ASIA score ($p < 0.05$ and $p < 0.001$, respectively). However, the addition of the IOSS injury grade to the initial ASIA motor score did not improve the predictive ability of the follow-up ASIA motor score. This was interpreted as indicating that the IOSS injury grade and initial ASIA motor score contain similar information about the extent of the traumatic spinal cord injury.

IOSS was compared with concurrently performed cervical spine MR images in 12 patients. IOSS confirmed parenchymal lesions demonstrated by MR (five patients), revealed cord lesions not detected by suboptimal MR studies (three patients), and better characterized lesions with early cyst formation (two patients). IOSS did not detect possibly significant herniated intervertebral disks in two patients because of its limited field of view.

***AJNR* 11:755–761, July/August 1990; *AJR* 155: September 1990**

Intraoperative spinal sonography (IOSS) has been shown to be useful in evaluating the acutely injured spinal cord by detecting and assessing the significance of displaced bone fragments, herniated disk material, epidural hematomas, spinal malalignment, residual thecal sac and spinal cord compression, and retained foreign bodies [1]. IOSS is also helpful in guiding the reduction of vertebral fractures/subluxations and in detecting the presence of posttraumatic cysts, either intra- or extramedullary, which may require shunting for management [1–3]. Quencer et al. [4] reported that IOSS is superior to CT with intrathecal contrast in its ability to differentiate spinal cord myelomalacia from intramedullary cysts and to estimate their size and number.

The value of IOSS for demonstrating, characterizing, and grading the type, severity, and outcome in a series of acute cervical spinal cord parenchymal injuries has not been reported to our knowledge. During an 18-month period we used

Received April 18, 1989; revision requested July 12, 1989; revision received November 29, 1989; accepted December 15, 1989.

[1] The Shock Trauma Center of the Maryland Institute for Emergency Medical Services Systems, Baltimore, MD 21201.

[2] Department of Diagnostic Radiology, University of Maryland Medical System, 22 S. Greene St., Baltimore, MD 21201. Address reprint requests to S. E. Mirvis.

[3] Department of Surgery, Division of Neurosurgery, University of Maryland Medical System, Baltimore, MD 21201.

[4] Department of Neurosurgery, Patuxent Medical Group, Baltimore, MD 21201.

0195–6108/90/1104–0755

IOSS to evaluate 30 spinal trauma patients with neurologic deficits referable to the cervical spinal cord injury who required laminectomy, posterior bone fragment removal, or anterior corpectomy for decompression of the neural elements and/or fixation as part of their initial medical management. A sonographic injury score, based on the size and sonographic character of lesions, was devised. This score was determined for each patient and compared with his initial and follow-up motor neurologic deficits. The IOSS score and location were additionally compared with concurrently performed cervical spine MR studies in 12 patients.

Methods and Materials

IOSS was performed in 30 adult patients (25 men and five women) 16–74 years old (mean, 43.9 years) from 1 to 39 days after cervical spine injury (mean, 12.4 days; 13 within 72 hr). All patients sustained neurologic deficits referable to cervical spinal cord injury. The initial neurologic deficits were classified as central cord syndrome (16), quadriplegia (eight), anterior cord syndrome (four), and radiculopathy (two). IOSS was performed with a 7.5 MHz sector transducer (Neurosector, ATL, Advanced Technology Labs, Bathell, WA). Twenty-five patients required laminectomy for spinal canal decompression and had IOSS images obtained via the posterior approach. These patients were operated on in the prone position and the surgical wound was filled with saline as both a sonographic coupling medium and a standoff. All the studies were technically satisfactory. Five patients had anterior corpectomy for management of severe hyperflexion/axial loading injuries with anterior interbody bone graft and Caspar plate fixation [5]. These patients were operated on in the supine position with the Caspar cervical retractors (Aesculap Instrument Corp., Burlingame, CA) in place. The cervical retractors held the scan head at 30–40 mm from the anterior cervical body. These anterior studies were technically suboptimal, since the spinal cord was beyond the focal plane of the transducer, and one study was considered uninterpretable. IOSS added only 5–10 min to the surgical procedure, with minimal risk to the patient.

All IOSS studies were recorded in real time on videotape, and selected images were later viewed and photographed for grading and lesion analysis. All patients reported in this study required bony decompression of the anterior or posterior spinal elements as dictated by their neurologic deficits, spinal fractures, and stabilization requirements. No patient had to have extra bone removed to allow IOSS to be performed or to provide a wider field of view.

Regions of altered echogenicity (increased or decreased) were evaluated in both the transverse and sagittal orientations to assess the volume of the injured spinal cord. Injury grade was based on the maximal diameter and character of abnormal parenchymal echogenicity in either imaging plane in the following manner:

Grade 0 — No area of altered echogenicity
Grade I — Focal increased echogenicity of < one half cord diameter
Grade II — Focal increased echogenicity > one-half and < full diameter of cord
Grade III — Increased echogenicity involving full diameter of cord
Grade IV — Increased echogenicity accompanied by cyst/syrinx formation within echogenic area

In addition, such epidural abnormalities as intervertebral disk herniation, bone fragment retropulsion, and epidural hematoma were noted. The motor neurologic deficit of the patients was assessed by the American Spinal Injury Association (ASIA) motor score classification [6] at admission and at follow-up in the 27 surviving patients with adequate IOSS for a period of 6 to 36 months in 21 patients and at 3 months in the remaining six patients.

Cervical spine MR (1.5 T, Siemens Magnetom) images were performed in 12 patients within 1 week of the IOSS except in one patient (Fig. 1) in whom MR was performed 18 days prior to IOSS. These studies were performed to clarify findings of radiography or spinal CT and to assess the cord for evidence of parenchymal abnormality. The patients were stabilized in a hard plastic cervical (Philadelphia) collar during the MR scan. This collar was considered adequate mechanical stabilization in this subgroup of spinal cord injury patients undergoing

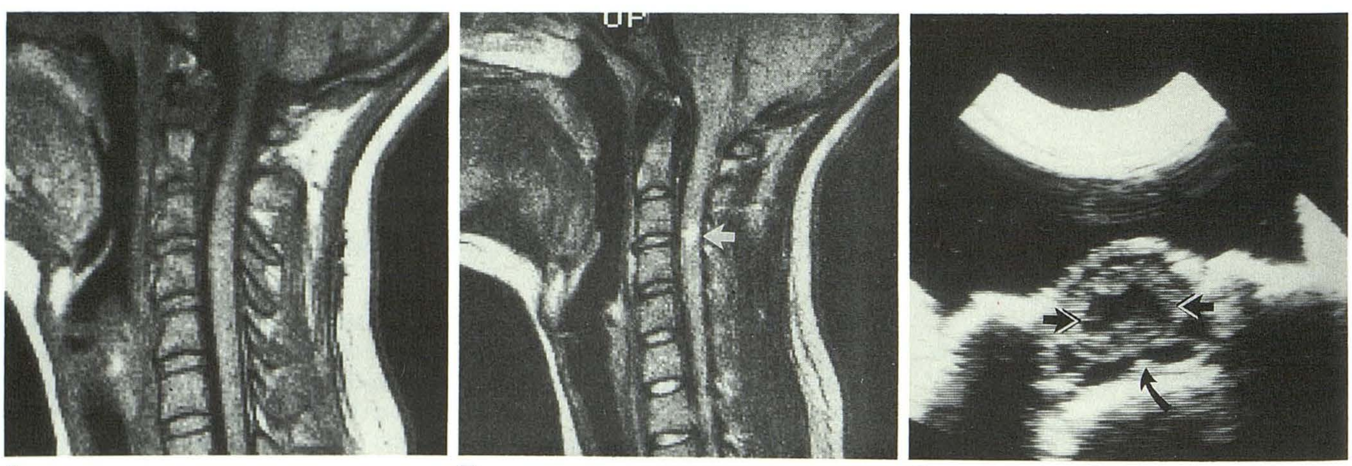
A B C

Fig. 1.—Grade IV lesion with cyst.

A, Mid-sagittal MR examination (SE 500/20) performed in 23-year-old woman with quadriplegia 2 weeks after trauma shows no definite focal parenchymal lesion.

B, Mid-sagittal MR examination (SE 2000/35) performed 3 weeks after trauma reveals area of increased signal at C3–C4 level (*arrow*) compatible with contusion or myelomalacia.

C, IOSS performed 5 weeks after trauma reveals uniform increased cord echogenicity with large central cavity (? necrosis) at C3–C4 level (*straight arrows*). A small midline posterior osteophyte is also observed (*curved arrow*). The cystic change may have developed in the 2-week interval between MR and IOSS. (Figs. 1A and 1B originally published in Mirvis SE, Geisler FH, Jelinek JJ, Joslyn JN, Gellad F. Acute cervical spine trauma: evaluation with 1.5-T imaging. *Radiology* 1988;166:807–816. Used with permission.)

MR, since they had mechanically stable central cord injuries. The plastic collar produced no MR artifacts across the spinal cord image and was tolerated well by the patients during the examination.

Results

IOSS was considered interpretable in 29 or 30 patients. Among these 29 patients, 32 separate spinal cord lesions were demonstrated (three patients had two lesions each). Parenchymal spinal cord lesions at the level of cervical fracture or stenosis that were compatible with the initial neurologic deficits were detected by IOSS in 28 (96.5%) of 29 patients with technically adequate studies. IOSS injury score was assigned on the basis of maximal grade of injury in either the sagittal or transverse image plane and included one patient with grade 0, two patients with grade I, 11 patients with grade II (Figs. 2–4), 11 patients with grade III (Figs. 5 and 6), and four patients with grade IV lesions (Figs. 1 and 7). Table 1 compares the IOSS injury grade with the admission and final ASIA motor scores.

The IOSS grade was correlated with the initial ASIA motor score ($p < 0.009$, Spearman's Rank Order Test), indicating that the IOSS echogenicity is related to the initial traumatic clinical motor deficit [7]. Regression analysis (see Appendix) demonstrated that both the IOSS injury grade and the initial ASIA score were correlated with the follow-up ASIA score ($p < 0.05$ and $p < 0.001$, respectively). However, the addition of the IOSS grade to the initial ASIA motor score did not improve the predictive ability of the follow-up ASIA motor score. This was interpreted as indicating that the IOSS grade and initial ASIA motor score contained similar information about the extent of the traumatic spinal cord injury.

IOSS also detected extradural abnormalities, including large posterior osteophytes indenting the spinal cord (three) (Figs. 5 and 6), residual anteriorly subluxed vertebral bodies (two), anterior epidural hematomas (two) (Fig. 2), asymmetric intervertebral disk herniation (one), retropulsed bone fragments compressing the anterior thecal sac (one), and a posteriorly subluxed vertebral body compressing the thecal sac and anterior spinal cord (Fig. 7). In all cases these abnormalities were previously diagnosed from radiographs, CT with intrathecal contrast, or MR prior to surgery.

Cervical spine MR images were compared with IOSS performed in 12 patients within 1 week of IOSS (Table 2). IOSS demonstrated 14 foci of increased echogenicity, including two separate foci in two patients, interpreted as parenchymal contusions. Two foci of decreased echogenicity were observed and interpreted as areas of intramedullary cyst formation in these patients. IOSS was equivalent to MR in demonstrating six parenchymal lesions in five patients (Figs. 3 and 6). IOSS detected six other parenchymal cord lesions not seen by MR (one grade III, four grade II, and one grade I lesions) in four other patients. Three of these studies were technically suboptimal owing to patient motion artifact (Fig. 4). Early parenchymal cyst formation was depicted by IOSS but not by MR in two patients (Fig. 1). MR demonstrated

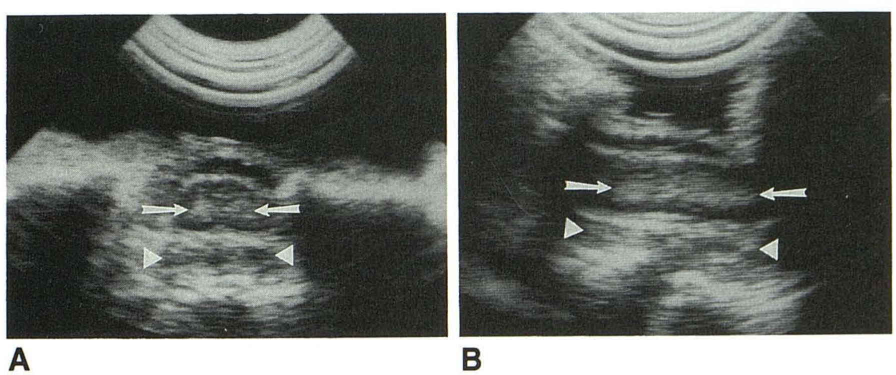

Fig. 2.—Grade II lesion with central gray localization.

***A* and *B*, IOSS performed in 63-year-old man with moderately severe anterior cord syndrome 1 day after trauma. Area of echogenicity occupies central portion of cord. Axial image reveals discrete echogenic foci in the central gray area of cord (*arrows*). Note increased echogenic region in anterior epidural space (*arrowheads*) believed to represent epidural hematoma.**

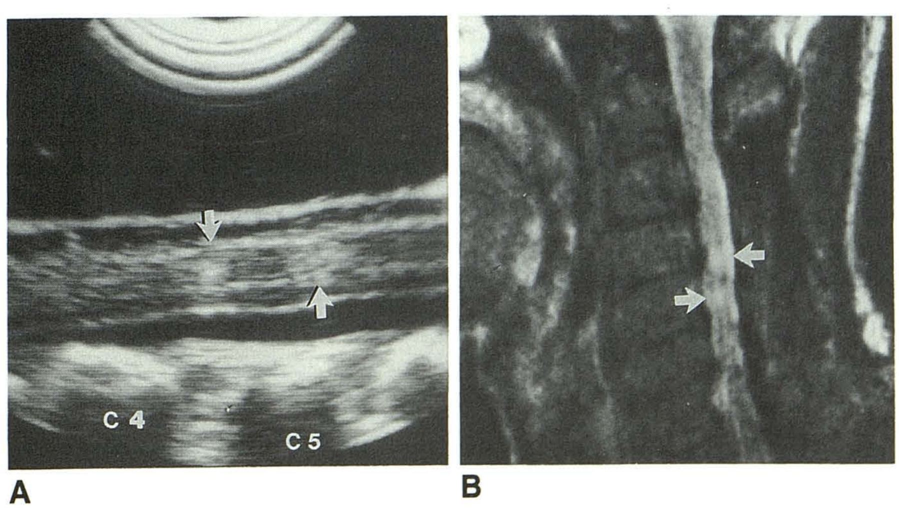

Fig. 3.—Grade II lesions with corresponding MR. IOSS performed in 33-year-old man with severe central cord syndrome 14 days after trauma.

***A*, Sonogram reveals two foci of increased echogenicity involving less than complete diameter of cord (*arrows*). One lesion is at disk level and more caudal lesion is at mid-body level.**

***B*, Corresponding MR examination (SE 2500/90) reveals two foci of increased signal at C4–C5 disk and at mid-C5 body (*arrows*) corresponding to IOSS. Small posterior osteophytes and spinal stenosis is noted from C3–C4 to C6–C7.**

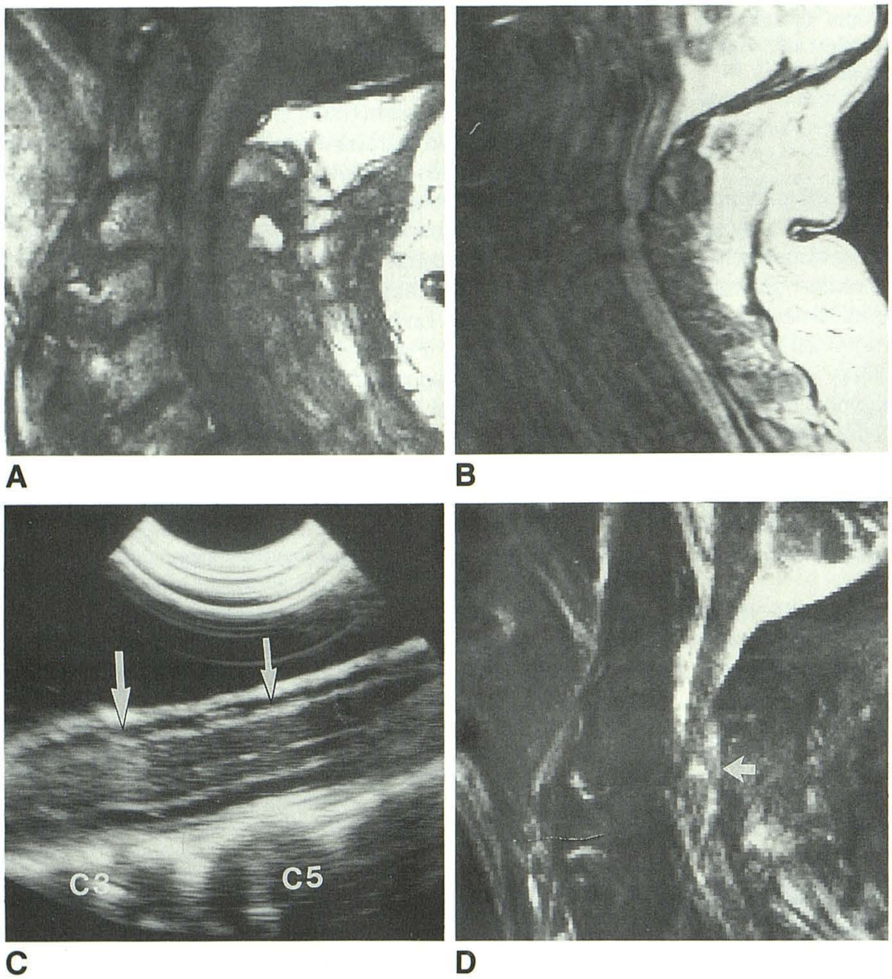

Fig. 4.—IOSS and corresponding MR.

A, Mid-sagittal MR (SE 500/17) obtained in 57-year-old woman after fall reveals large osteophyte at C3–C4 in contact with anterior spinal cord.

B, Mid-sagittal MR (SE 2500/90) is compromised by motion, but reveals indentation of anterior and posterior spinal cord at C3–C4. No parenchymal lesion is discerned.

C, IOSS study performed after laminectomy 5 days after MR study reveals an area of increased echogenicity posteriorly at C3–C4 and possibly posteriorly at C5 (*arrows*).

D, Follow-up mid-sagittal MR (SE 2500/90) performed 40 days after surgery reveals increased signal at C3–C4 (*arrow*) corresponding to lesion observed by IOSS.

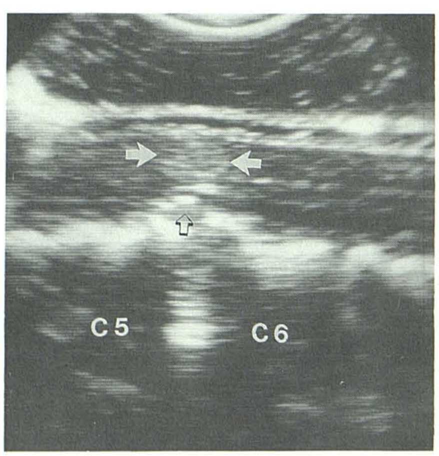

Fig. 5.—Grade III cord lesion. IOSS performed in 57-year-old man with central cord syndrome 14 days after trauma reveals increased echogenic area (*solid arrows*) extending across entire cord diameter. Lesion is centered at level of posterior osteophyte (*open arrow*).

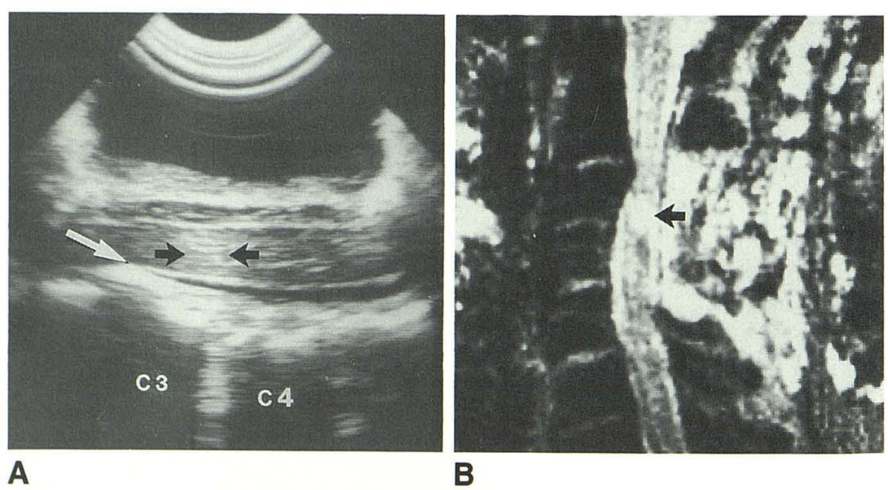

Fig. 6.—IOSS and corresponding MR.

A, IOSS obtained in 34-year-old man after motor vehicle accident reveals grade III echogenic area at C3 level (*black arrows*) just below large C2–C3 osteophyte (*white arrow*).

B, Corresponding MR (GRE 200/18, angle 10°) performed after C3, C4, and partial C5 laminectomy reveals increased signal at C3 compatible with contusion (*arrow*).

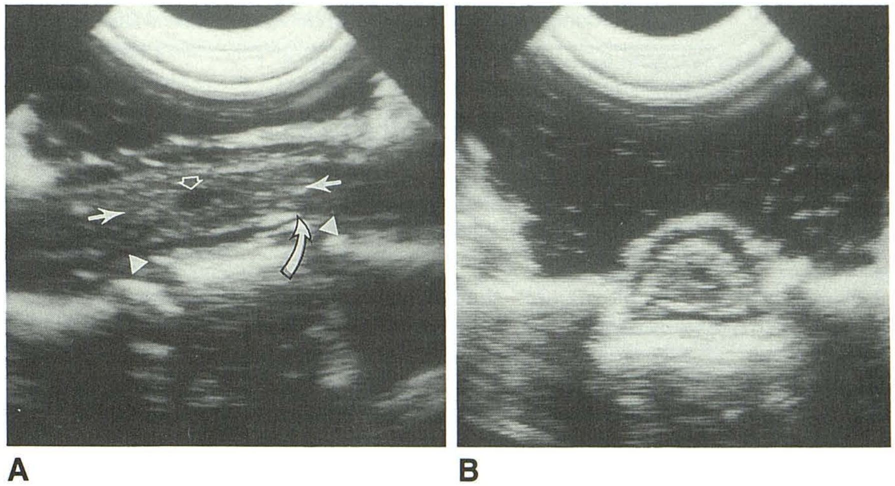

Fig. 7.—Grade IV lesion with cyst formation. IOSS performed in 25-year-old man with severe central cord syndrome 15 days after trauma.

A, Longitudinal image reveals large area of increased echogenicity (*solid straight arrows*) at level of retropulsed vertebral body (*arrowheads*). Note slight anterior indentation of cord (*curved arrow*). Central area of echolucency is compatible with cyst (*open arrow*) formation (? liquefaction).

B, Axial image also demonstrates focus of cyst formation surrounded by echogenic contusion.

TABLE 1: IOSS Injury Grade Versus Initial and Final ASIA Motor Score (0–100 Range)

IOSS Injury Grade[1]	Number of Patients[2]	Initial ASIA Motor Score[3] Mean and Range	Follow-up[4] ASIA Motor Score Mean and Range
0	1	84 (84)	98 (98)
I	2	97.5 (97–98)	99 (98–100)
II[5]	10	43.2 (22–89)	82.1 (41–98)
III[6]	10	45.6 (1–86)	73.5 (10–100)
IV[7]	4	8.5 (0–14)	27.8 (0–59)

[1] IOSS injury grade determined by the maximum diameter of echogenicity in the sagittal and transverse image planes.

[2] The total number of patients with IOSS injury grade and follow-up is 27 of the 30 patients (two deaths and one technically inadequate IOSS study).

[3] The ASIA motor score has a range of 0 (complete quadriplegia) to 100 (normal motor function). It is determined by adding the muscle strengths (0–5 point strength scale) for five key muscles in each extremity.

[4] Follow-up ASIA motor scores were determined from 6 to 36 months after injury in 21 patients and at 3 months in the remaining six patients.

[5] In this group one patient died before follow-up and two patients had two grade II lesions.

[6] In this group one patient died before follow-up and one patient had two grade III lesions. One patient had a concurrent grade II lesion and is included in this group for analysis.

[7] All patients had cystic changes within areas of increased echogenicity.

herniated intervertebral disks in two patients that were not visualized on IOSS because of the restriction in the field of view of the IOSS study. Pathologic confirmation of parenchymal contusions or cysts was not obtained in any patient, since no spinal cord biopsies were performed and autopsies were not performed in two patients who died.

Discussion

IOSS has previously been applied to diagnosis and management of spinal trauma. Montalvo et al. [3] have shown that IOSS can detect bone fragments, spinal malalignment, cord or thecal sac compression, foreign bodies, and late complications of spinal cord injury, including myelomalacia and posttraumatic intramedullary and subarachnoid cysts. IOSS can guide the surgical decompression of the spinal cord and help obtain anatomic reduction [1–4]. While the role of IOSS in making the important distinction between posttraumatic cyst/syrinx and myelomalacia in the chronically injured spinal cord has been emphasized [3], the potential value of IOSS in defining lesions of the spinal cord in the acute and subacute phases of injury has not been addressed.

We performed IOSS on 30 patients with cervical spinal trauma resulting in neurologic deficits who required removal of anterior or posterior bony elements for surgical bony decompression and fixation of the spine with exposure of the dura. This study evaluates the ability of IOSS to detect and quantify spinal cord parenchymal injury and to compare its ability with the initial neurologic deficit as assessed by the ASIA motor score to predict the potential for recovery of neurologic function. Abnormalities of spinal cord echogenicity were detected in 28 of 29 patients with technically adequate studies. Most lesions in the acute or subacute period after trauma appeared as areas of well demarcated focally increased echogenicity. Montalvo et al. [3] have speculated that this increase in echogenicity in the early postinjury phase represents areas of contusion, edema, and hemorrhage. Since echogenicity is attributed to increased acoustic interfaces, it seems reasonable to postulate that edema or microhemorrhages infiltrating layers of neural tissue may account for the echogenic appearance of these early spinal lesions [8]. In four patients areas of cyst formation within zones of increased echogenicity were detected by IOSS performed 15 to 37 days (mean, 20.5 days) after injury. The appearance of cystic changes on IOSS may depend on how long after injury the study is performed.

The initial motor level of neurologic deficit and the IOSS injury score were both predictive of the follow-up motor neurologic deficit in this group of patients as determined by regression analysis. Exact prediction of recovery of neurologic function after spinal trauma in a particular patient is complex and includes factors such as initial deficit (complete versus incomplete deficit), timing and completeness of spinal cord decompression, age, type and force of injury, other associated injuries, initial hemodynamic stability, medical complica-

TABLE 2: Comparison of IOSS and MR Images of Spinal Cord Injury in 12 Patients

Case No.	Age (yrs)	Sex	IOSS Findings	MR Findings	IOSS Versus MR
1	46	M	Grade III lesion at C3–C4 disk level	Focus of increased T2-weighted signal at C3–C4 consistent with contusion	IOSS = MR
2	33 (Fig. 3)	M	Two grade II lesions at C4–C5 and mid-C5	Two foci of increased T2-weighted signal consistent with contusions at C4–C5 and mid-C5	IOSS = MR
3	34 (Fig. 6)	M	Grade III lesion at C3; large posterior osteophyte at C2–C3	Focal increased T2-weighted signal at C3 consistent with contusion; large posterior osteophyte at C2–C3	IOSS = MR
4	52	M	Grade IV lesion; upper cervical cord atrophy; echogenic area at C1 with adjacent small cystic area	Increased T2-weighted signal at C1 consistent with contusion; spinal stenosis at C1	IOSS > MR for cyst demonstration
5	74	F	Grade II lesion in central gray matter at C4–C5 with C4–C5 disk herniation	No cord lesion seen[1]	IOSS > MR for cord lesion
6	57	M	Grade III lesion at C3–C4; spondylitic changes at C3–C4 and C4–C5	Increased T2-weighted signal at C3–C4 consistent with contusion	IOSS = MR
7	68	M	Grade II lesion at C4–C5; grade III lesion at C3–C4; posterior osteophyte at C3–C4; herniated disk at C4–C5	No cord lesions seen[1]; herniated disks at C2–C3, C3–C4, and C4–C5	IOSS > MR for cord lesion; IOSS < MR for herniated disks
8	17	M	Grade I cord lesion; C4–C5 subluxation	C4–C5 subluxation; no cord lesion; laceration of PLL; occlusion of left vertebral artery	IOSS > MR for cord lesion; IOSS < MR for injury to artery/PLL
9	39	M	Grade II lesion; central cord lesion; C4–C5 disk herniation	Focal increased T2-weighted signal at C4–C5 consistent with contusion; minimal disk herniation at C4–C5	IOSS = MR
10	23 (Fig. 1)	F	Grade IV lesion; echogenic cord with cystic area centrally at C3–C4	Focal increased T2-weighted signal at C3–C4 consistent with contusion	IOSS > MR for cyst demonstration
11	52	M	Grade III lesion at C6; cervical spondylosis	Herniated disk at C3–C4; focal increased signal at C6 consistent with contusion	IOSS > MR for cord lesion; IOSS < MR for herniated disk
12	57 (Fig. 4)	F	Grade II lesions at C3–C4 and C4–C5; posterior osteophytes at both levels; cord indented anteriorly at C3–C4	Spinal stenosis at C3–C4 adjacent to posterior osteophyte; no definite parenchymal lesions[1]	IOSS > MR for cord lesions

Note.—IOSS = intraoperative spinal sonography, PLL = posterior longitudinal ligament.
[1] MR was suboptimal technically owing to excessive motion.

tions resulting from the injury, and the presence or absence of spinal cord atrophy [9–13].

The IOSS injury grading system for parenchymal spinal cord injuries devised and presented here was based on a semiquantitative measurement of volume of injury as imaged in two orthogonal image planes. Areas of cyst formation within the cord suggest a more serious injury, most likely breakdown of cord hematomas and/or early liquefaction necrosis of infarcted neural tissue. Thus, lesions with this finding were classified with a higher injury severity score. The range of neurologic deficit both initially and at follow-up, as indicated by the ASIA motor score, varied widely within each injury grade. Although a statistically significant correlation between the IOSS injury grade and final ASIA motor score was demonstrated, this had a lower correlation significance than between the initial and final ASIA motor deficits. Thus, IOSS did not increase the ability to predict the motor neurologic outcome in this limited series.

IOSS is a highly sensitive technique to detect and confirm the presence or absence of spinal cord injury following trauma. The extent and character of sonographically detected cervical spinal cord lesions correlates with the extent of clinical neurologic motor deficit, but its knowledge adds little additional predictive value for recovery of motor function. IOSS appears to be as sensitive, and in some cases more sensitive, as MR for detecting spinal cord injury, and it is particularly useful if the MR is suboptimal or cannot be performed. The restriction of spinal canal sonography to surgically managed patients and its relatively limited field of view are obvious limitations of the technique. However, if the surgical opportunity presents itself, IOSS is an easy method of acquiring intraoperative morphologic details of the spinal cord and its interrelationship with the spinal column.

Appendix

IOSS Grade and Initial ASIA Motor Score Versus Final ASIA Motor Score Regression Analysis

Regression Trial	Independent Variable	Slope	Coefficient of Determination (%)
1	IOSS[1]	−14.9	20.0
2	Initial ASIA[2]	0.683	51.8
3	Initial ASIA and	−2.69	52.3
	IOSS[2]	0.642	

Note.—Dependent variable = final ASIA score.
[1] $p < .05$
[2] $p < .001$

REFERENCES

1. Rubin JM, Dohrman GJ. The spine and spinal cord during neurosurgical operations: Real-time ultrasonography. *Radiology* **1985**;155:197–200
2. Quencer RM, Montalvo BM, Eismont FJ, Green BA. Intraoperative spinal sonography in thoracic and lumbar fractures: evaluation of Harrington rod instrumentation. *AJNR* **1985**;6:353–359, *AJR* **1985**;145:343–349
3. Montalvo BM, Quencer RM, Green BA, Eismont FJ, Brown MJ, Brost P. Intraoperative sonography in spinal trauma. *Radiology* **1984**;153:125–134
4. Quencer RM, Morse BMM, Green BA, Eismont FJ, Brost P. Intraoperative spinal sonography: adjunct to metrizamide CT in the assessment and surgical decompression of posttraumatic spinal cord cysts. *AJNR* **1984**;5:71–79
5. Caspar W, Barbier DD, Klara PM. Anterior cervical fusion and Caspar plate stabilization for cervical trauma. *Neurosurgery* **1989**;25:491–502
6. American Spinal Injury Association. ASIA-standards for neurologic classification of spinal injury patients. Chicago: American Spinal Injury Association, **1984**
7. Spearman C. The proof and measurement of association between two things. *Am J Psychol* **1904**;15:72–101
8. Saul TG, Ducker TB. Treatment of spinal cord injury. In: Cowley RA, Trump BF. *Pathophysiology of shock: anoxia and ischemia.* Baltimore, MD: Williams & Wilkins, **1982**: Ch. 45, 624–640
9. Gertzbein SD, Court-Brown CM, Marks P, et al. The neurologic outcome following surgery for spinal fractures. *Spine* **1988**;13:641–644
10. Ducker TB, Salcman M, Danielle HB. Experimental spinal cord trauma. III: Therapeutic effect of immobilization and pharmacologic agents. *Surg Neurol* **1978**;10:71–76
11. Gardner BP, Theocleous F, Krishman KR. Outcome following acute spinal cord injury: a review of 198 patients. *Paraplegia* **1988**;26:94–98
12. Tator CH, Duncan EG, Edmonds VE, Lapczak LI, Andrews DF. Comparison of surgical and conservative management in 208 patients with acute spinal cord injury. *Can J Neurol Sci* **1987**;14:60–69
13. Ducker TB, Lucas JT, Wallace CA. Recovery from spinal cord injury. *Clin Neurosurg* **1983**;30:495–513