Spinal Trauma

While at the present time the cranium is not being studied routinely by MR in cases of trauma, the spinal column presents an ideal situation for the study of trauma from the acute through the chronic phases. The reason for this is that computed tomography of the cranium often adequately delineates the traumatic pathology affecting the intracranial neural tissue. In the spinal column however, although computed tomography is excellent for the evaluation of bony trauma, the spinal neural tissue is usually not adequately visualized. On the other hand, MR demonstrates traumatic change quite well within the spinal cord and epidural tissues (Mayer and Kulkarni, 1987; Takahashi et al., 1987; Mathis et al., 1988; Mirvis et al., 1988; Pan et al., 1988; Emery et al., 1989; Flanders et al., 1990; Mendolsohn et al., 1990; Kerslake et al., 1991; Curati et al., 1992; Silberstein et al., 1992; Bashir et al., 1993; Davis et al., 1993; Kliewer et al., 1993; Post et al., 1994; Leite et al., 1997; Jinkins, 1998a,b; Jinkins et al. 1998).

CONVENTIONAL FAST SPIN ECHO AND GRADIENT-RECALLED ECHO ACQUISITIONS

BASIC PROTOCOL

Although computed tomography (CT) and conventional radiography can be used to show gross traumatic alterations affecting the spinal column itself and the perispinal soft tissues, the contents of the spinal canal are not accurately delineated using these techniques. Magnetic resonance (MR), on the other hand, excellently images the spinal cord and subarachnoid space, and often the individual spinal nerve roots. In addition, MR is also able, in many respects, to accurately and sensitively evaluate the elements of the spinal column and perispinal soft tissues, and coupled with an intravenously administered contrast agent (e.g., gadolinium, Gd), it can assess the integrity of the blood–central nervous system (CNS) barrier (i.e., the combined blood-cord, the blood-nerve, and the relative blood-meningeal barriers; Jinkins, 1993a,b; 1999).

The following sequences comprise the preferred protocol for high-field MR machines. In most or all cases of acute trauma, gradient-recalled echo acquisitions may be desirable in order to search for acute blood products (i.e., deoxyhemoglobin). In addition, occasionally intravenous (i.v.) contrast enhanced alternate protocols may be useful to evaluate the integrity of the blood-nerve barrier in certain cases of suspected compressive radiculopathy.

Table A8.6.1 lists the hardware necessary to perform the procedure, along with appropriate parameters. The available gradient strength will depend on the scanner, and the echo times (e.g., T_E) given in other tables will be varied accordingly (the smaller the gradient strength, the longer the echo time for a particular scan).

This entire protocol should take 45 to 50 min to complete.

Table A8.6.1 Equipment Parameters for Spine Imaging in Cases of Spinal Trauma

Coil type	Cervical, thoracic, lumbar: phase array surface coil (or other depending upon machine compatibility and availability)
Peripheral gating	Thoracic spine only (optional)
Flow compensation	Any level (optional, if available)
Respiratory gating	Thoracic spine only (optional)
Use of contrast agent	Yes

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Current Protocols in Magnetic Resonance Imaging (2002) A8.6.1-A8.6.12

NOTE: Be sure that technicians and nurses have immediate access to any emergency equipment that may be relevant to a given study, or that may be needed for a particular patient, such as crash carts or oxygen.

Set up patient and equipment

1. Interview (screen) the patient to ensure that he or she has no contraindications such as cardiac pacemakers or other implants containing ferromagnetic materials. Also be sure to find out if the patient has any health conditions that may require the presence of special emergency equipment during the scanning procedure, or necessitate any other precautions.

   Generally standard screening forms are used for all patients scanned in a magnetic resonance system.

   The presence of any ferromagnetic metals may be a health hazard to the patient when he or she is inside the magnet, and will also affect the imaging. If in doubt as to the exact composition of the items, it is best to exclude patients with any metal implants; see Shellock (1996) for discussion of what implants may be safely scanned using magnetic resonance.

   Patients may be accompanied into the magnet room by a friend or family member, who can sit in the room during the scan and comfort the patient as needed. This companion must be screened as well to ensure the absence of loose metal objects on the body or clothing.

2. If the procedure is a research protocol, have the patient sign any necessary consent form.

3. Have the patient remove all jewelry and change into a gown to eliminate any metal that might be found in clothing.

4. Inform the patient about what will occur during the procedure, what he or she will experience while in the magnet, and how to behave, including the following.

   a. If earphones or headphones are used to protect the ears from the loud sounds produced by the gradients, the patient will be asked to wear these, but will be able to communicate with you at any time during the imaging.
   b. The patient will be given a safety squeeze-bulb or similar equipment to request assistance at any time (demonstrate how this works).
   c. For good results the patient should not talk, and should avoid or minimize swallowing or other movement, during each scan—i.e., as long as the banging sounds continue. Between scans, talking and swallowing are allowed in most cases, but should be avoided when comparative positional studies are being performed; the patient will be informed when this is the case.
   d. Nevertheless, the patient may call out at any time if he or she feels it necessary.

5. Have the patient mount onto the table. Either before or right after the patient lies down, set up any triggering devices or other monitoring equipment that is to be used.

6. Center the coil over the region where the key information is desired.

   Make sure that the body is constrained to prevent motion, especially if high-resolution scans are to be run.

7. If needed, place a pillow or other support under the knees to make the patient more comfortable.

8. Use the centering light to position the patient (cervical spine: thyroid cartilage; thoracic spine: nipple line; lumbar spine: iliac crests) and put him or her into the center of the magnet.

Table A8.6.2 Primary Clinical Imaging Parameters for Sequence 1 (Pilot Scan)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Centered on: Cervical spine: thyroid cartilage Thoracic spine: nipple line Lumbar spine: iliac crests
Echo time (T_E)	As short as possible
Repeat time (T_R)	As short as possible
Flip angle (FA)	15°
Fields of view (FOV_x, FOV_y)	Cervical: 240 mm, 240 mm Thoracic: 320 mm, 320 mm Lumbosacral: 280 mm, 280 mm
Resolution (Δx, Δy)	Cervical: 0.94 mm, 0.94 mm Thoracic: 1.25 mm, 1.25 mm Lumbosacral: 1.09 mm, 1.09 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Slice gap	Not applicable
Number of acquisitions (N_{acq})	1
Scan time	~10 sec

Once this step has been performed, so long as the patient does not move on the table, the table itself can be moved and then replaced in the same position as before without jeopardizing the positioning of one scan relative to another.

9. If the patient is unable to hold still, provide an appropriate sedative.

Sequence 1: Rapid positioning pilot

10. To validate the patient's position, run the system's pilot (or scout) scan (sequence 1) to ensure correct location of the neck in three dimensions, using the imaging sequence given in Table A8.6.2 or similar parameters.

    This sequence usually consists of three orthogonal planes to allow subsequent localization. The images are often also used later to determine where to place the saturation pulses and to set up total coverage of the volume of interest.

Sequence 2: Sagittal T_1-weighted conventional spin echo

11. Set the imaging parameters as shown in Table A8.6.3.

12. Use the pilot image to locate the spine in three dimensions to ensure coverage of the region of interest (e.g., cervical, thoracic, lumbosacral spine).

13. Let the patient know you are ready and begin the scan.

Sequence 3: Sagittal T_2-weighted fast spin echo, fat suppressed

Fat suppression is necessary to determine vertebral marrow edema in cases of frank or occult bony fracture and in visualizing spinal ligament injury/rupture (Emery et al., 1989; Kliewer et al., 1993).

14. Review the pilot scans and ensure that the saturation pulse is correctly placed anterior to above the slab of interest.

Table A8.6.3 Primary Clinical Imaging Parameters for Sequence 2 (T_1-Weighted Image)

Patient position	Supine
Scan type	Conventional spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Centered on: Cervical: 3rd cervical vertebra Thoracic: 6th thoracic vertebra Lumbar: 3rd lumbar vertebra
Echo time (T_E)	10 msec
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	Cervical: 240 mm, 240 mm Thoracic: 320 mm, 320 mm Lumbosacral: 280 mm, 280 mm (may use rectangular field of view, e.g., half or three-quarter field, if available, or tailor to region of interest)
Resolution (Δx, Δy)	Cervical: 0.94 mm, 0.94 mm Thoracic: 1.25 mm, 1.25 mm Lumbosacral: 1.09 mm, 1.09 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	Cervical: 3 mm Thoracic: 3 mm Lumbar: 4 mm
Number of slices	10, or more, as needed to cover the region of interest
Slice gap	Cervical: 0.5 mm Thoracic: 1 mm Lumbar: 1 mm
Number of acquisitions (N_{acq})	2
Flow compensation	Yes (if available)
Saturation pulses	Yes; anterior cervical/thoracic/lumbar slab to saturate larynx/vessels
Slice series	Left to right or the reverse depending on preference
Scan time	~4 min

15. Run sequence 3 according to Table A8.6.4.

Sequence 4: Transverse T_1-weighted conventional spin echo

16. Using the midline sagittal T_1-weighted image acquired in sequence 2, set the transverse acquisition parameters as follows:
    a. Cervical spine: stacked images from C1 through C7-T1.
    b. Thoracic spine: stacked images through levels of interest.
    c. Lumbosacral spine: 5 slices each, angled to the plane of the intervertebral disc at L3-4, L4-5, and L5-S1; one slice each, angled to the intervertebral disc at L1-2 and L2-3.
17. Supplement additional slices according to visible disease present or to clinical query.
18. Run the sequence according to Table A8.6.5.

Table A8.6.4 Primary Clinical Imaging Parameters for Sequence 3 (T_2-Weighted Image, Fast Spin Echo)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Centered on area of interest (as in sequence 2, Table A8.6.3)
Echo time (T_E)	100 msec
Echo train length (ETL)	8
Repeat time (T_R)	4000 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	As in Sequence 2, Table A8.6.3
Resolution (Δx, Δy)	Cervical: 0.47 mm, 0.47 mm Thoracic: 0.63 mm, 0.63 mm Lumbosacral: 0.55 mm, 0.55 mm
Number of data points collected (N_x, N_y)	512, 512
Display matrix (D_x, D_y)	512, 512
Slice thickness (Δz)	Cervical: 3 mm Thoracic: 3 mm Lumbar: 4 mm
Number of slices	Varies with spinal level
Slice gap	Cervical: 0.5 mm Thoracic: 1 mm Lumbar: 1 mm
Number of acquisitions (N_{acq})	1
Flow compensation	Yes (if available)
Saturation pulses	Yes; anterior cervical/thoracic/lumbar slabs to saturate larynx/vessels/heart
Fat suppression	Yes; chemical saturation or STIR (short tau inversion recovery)
Slice series	Left to right or the reverse depending on preference
Scan time	~4 min

Sequence 5: Transverse T_2-weighted fast spin echo

19. Using the midline T_1-weighted image acquired in sequence 2, repeat the setup as in Table A8.6.6.

20. Run sequence 5 according to Table A8.6.6.

Sequence 6: Sagittal gradient-recalled echo

Gradient-recalled echo acquisitions may be used in the sagittal and/or transverse planes to clearly distinguish between various types of hemorrhage and to clearly identify acute blood products (e.g., deoxhemoglobin). Fast spin echo sequences will overlook this type of hemorrhage.

21. Run the sequence according to Table A8.6.7.

Sequence 7: Transverse gradient-recalled echo

22. Run the sequence according to Table A8.6.8.

Table A8.6.5 Primary Clinical Imaging Parameters for Sequence 4 (T_1-Weighted Image)

Patient position	Supine
Scan type	Conventional spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Centered on the area of interest (as in sequence 2, Table A8.6.3)
Echo time (T_E)	10 msec
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	As in sequence 2, Table A8.6.3
Resolution (Δx, Δy)	Cervical: 0.94 mm, 0.94 mm Thoracic: 1.25 mm, 1.25 mm Lumbosacral: 1.09 mm, 1.09 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	Cervical: 3 mm Thoracic: 3–8 mm Lumbar: 4 mm
Number of slices	Varies with spinal level
Slice gap	Cervical: 1 mm Thoracic: 1–2 mm Lumbar: 1 mm
Number of acquisitions (N_{acq})	2
Slice locations	See text (Basic Protocol, step 16)
Saturation pulses	No
Scan time	~4 min

Table A8.6.6 Primary Clinical Imaging Parameters for Sequence 5 (T_2-Weighted Image, Fast Spin Echo)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Centered on the region of interest (as in sequence 2, Table A8.6.3)
Echo time (T_E)	100 msec
Echo train length (ETL)	8
Repeat time (T_R)	4000 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	As in sequence 2, Table A8.6.3
Resolution (Δx, Δy)	Cervical: 0.94 mm, 0.94 mm Thoracic: 1.25 mm, 1.25 mm Lumbosacral: 1.09 mm, 1.09 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	Cervical: 3 mm Thoracic: 3–8 mm Lumbar: 4 mm
Number of slices	Varies with spinal level
Slice gap	Cervical: 1 mm Thoracic: 1–2 mm Lumbar: 1 mm
Number of acquisitions (N_{acq})	2
Slice locations	See text (Basic Protocol, step 16)
Saturation pulses	No
Scan time	~4 min

Table A8.6.7 Primary Clinical Imaging Parameters for Sequence 6 (T_2^* Gradient-Recalled Echo)

Patient position	Supine
Scan type	2-D gradient echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Centered on the region of interest (as in sequence 2, Table A8.6.3)
Echo time (T_E)	15 msec
Repeat time (T_R)	500 msec
Flip angle (FA)	10° to 20°
Fields of view (FOV_x, FOV_y)	As in sequence 2
Resolution (Δx, Δy)	Cervical: 0.94 mm, 0.94 mm Thoracic: 1.25 mm, 1.25 mm Lumbosacral: 1.09 mm, 1.09 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	3 mm
Number of slices	Varies with spinal level
Slice gap	≤1 mm
Number of acquisitions (N_{acq})	3
Flow compensation	Yes (if available)
Saturation pulses	Yes
Scan time	~6 min

Table A8.6.8 Primary Clinical Imaging Parameters for Sequence 7 (T_2^* Gradient-Recalled Echo)

Patient position	Supine
Scan type	2-D gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Centered on the region of interest (as in sequence 2, Table A8.6.3)
Echo time (T_E)	15 msec
Repeat time (T_R)	500 msec
Flip angle (FA)	10° to 20°
Fields of view (FOV_x, FOV_y)	As in sequence 2, Table A8.6.3
Resolution (Δx, Δy)	Cervical: 0.94 mm, 0.94 mm Thoracic: 1.25 mm, 1.25 mm Lumbosacral: 1.09 mm, 1.09 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	3-4 mm
Number of slices	Varies with spinal level
Slice gap	≤1 mm
Number of acquisitions (N_{acq})	1
Slice locations	See text (Basic Protocol, step 16)
Saturation pulses	Yes
Scan time	~2 min

ALTERNATE PROTOCOL

CONTRAST ENHANCED ACQUISITIONS

For some situations, such as an MRI scan that has findings that do not match the clinical findings, an i.v. paramagnetic contrast material may be indicated.

Materials

Normal saline (0.9% NaCl), sterile
Extravascular contrast agent (e.g., Magnevist, Omniscan, or Prohance)

Set up patient and equipment

1. Use the same equipment and perform equipment and patient setup as in the Basic Protocol (steps 1 to 4).
2. Establish an intravenous line from which the contrast agent can be injected, and attach this line securely to the patient so that movement into or out of the magnet will not pull at the patient's arm. Resume steps 5 to 9 in the Basic Protocol.

   It is preferable to insert the line prior to imaging and to leave the patient in the magnet, with no intervening motion, between the scans run before contrast agent injection and those run after injection.

Scan pilot

3. Run a rapid three-plane positioning pilot scan (see Basic Protocol, sequence 1).

Sequences 8 and 9: Contrast enhanced scans

4. Leaving the patient in the magnet, inject the contrast agent, flush the i.v. line with 10 ml saline, and then immediately run sagittal (sequence 8) and transverse (sequence 9) T_1-weighted image sequences (see Basic Protocol, sequences 2 and 4; sequences 8 and 9 are the same as sequences 2 and 4, respectively, but with the contrast agent injected into the patient).

   A dose of 0.1 mmol/kg of contrast agent is usually given.

COMMENTARY

Background Information

The special structures that are involved in the process of trauma include the spinal column, related ligaments and attached muscles, the dura, arachnoid, and pia, the spinal cord, nerve roots or spinal nerves, and the regional blood vessels. It is important to note that what is observed on the imaging will depend upon not only the structures involved, but also the severity of the injury and the timing of the imaging study in relation to the traumatic incident. As is true of all traumas to tissues, there will be a temporal evolution of the pathophysiology, and this will in part be reflected in the imaging findings.

Direct nonpenetrating and penetrating trauma are two of the most common forms of trauma encountered in clinical practice. Many of the injuries to the spinal column, neural tissue, and vascular tissue involved are excellently evaluated both in the acute and chronic phases by MR imaging (Fig. A8.6.1; Jinkins, 1998a,b). In medical imaging, there is a continuing dilemma between deciding what can be done and what should be done in any given patient. In the case of trauma to the spine, the benefits of MR imaging include the advantage of superior spatial and contrast resolution in multiple planes, the possibility of specific tissue characterization (e.g., hemorrhage), and the relative ability to gain potentially prognostic information noninvasively (Fig. A8.6.2). The drawbacks of MR imaging include the need to work with unstable patients, perhaps in traction and on life support devices, the difficulty of performing examinations on a 24-hr emergency basis, the overall expense of the examination, and the inability of MR scan to detect nondeforming spinal fractures. In addition, it remains true that many patients have a poor prognosis in spite of undergoing either medical imaging procedures or extended treatment regimens. In the future, progressive new therapies may change this situation. Ideally, MR imaging

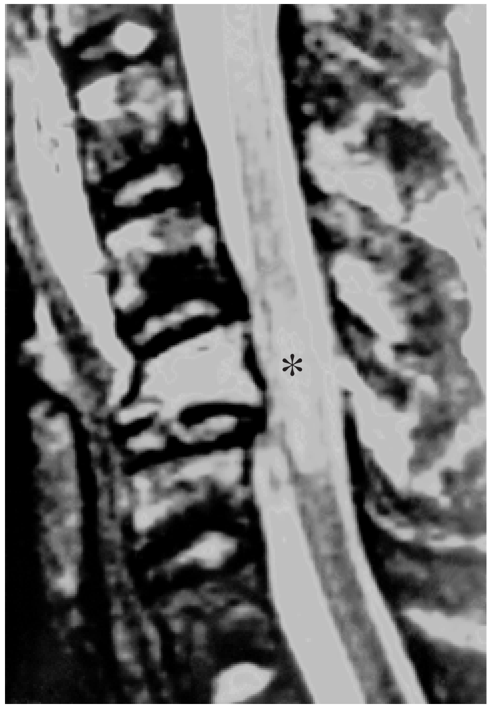

Figure A8.6.1 Spinal cord contusion. Sagittal T_2-weighted (T_R = 4000 msec, T_E = 100 msec) MR shows multiple areas of spinal column marrow hyperintensity indicating bony injury and hyperintensity within the cervical spinal cord (asterisk) indicating contusion.

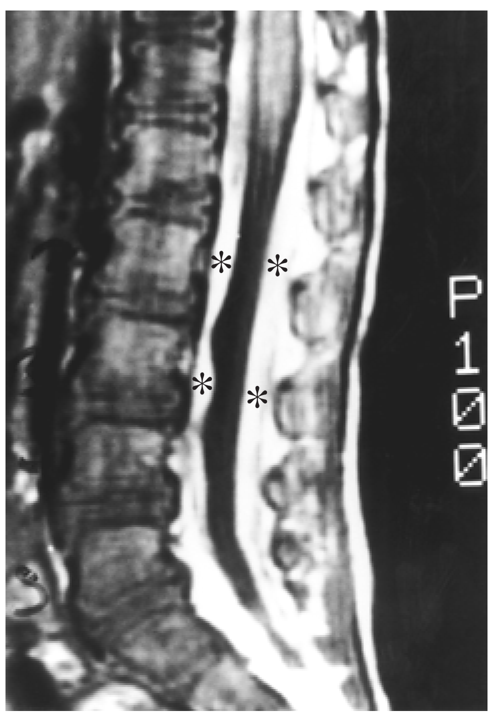

Figure A8.6.2 Traumatic epidural intraspinal hematoma. Sagittal T_1-weighted (T_R = 500 msec, T_E = 10 msec) image shows hyperintense epidural hematoma formation throughout the thoracolumbar area anteriorly and posteriorly (asterisks).

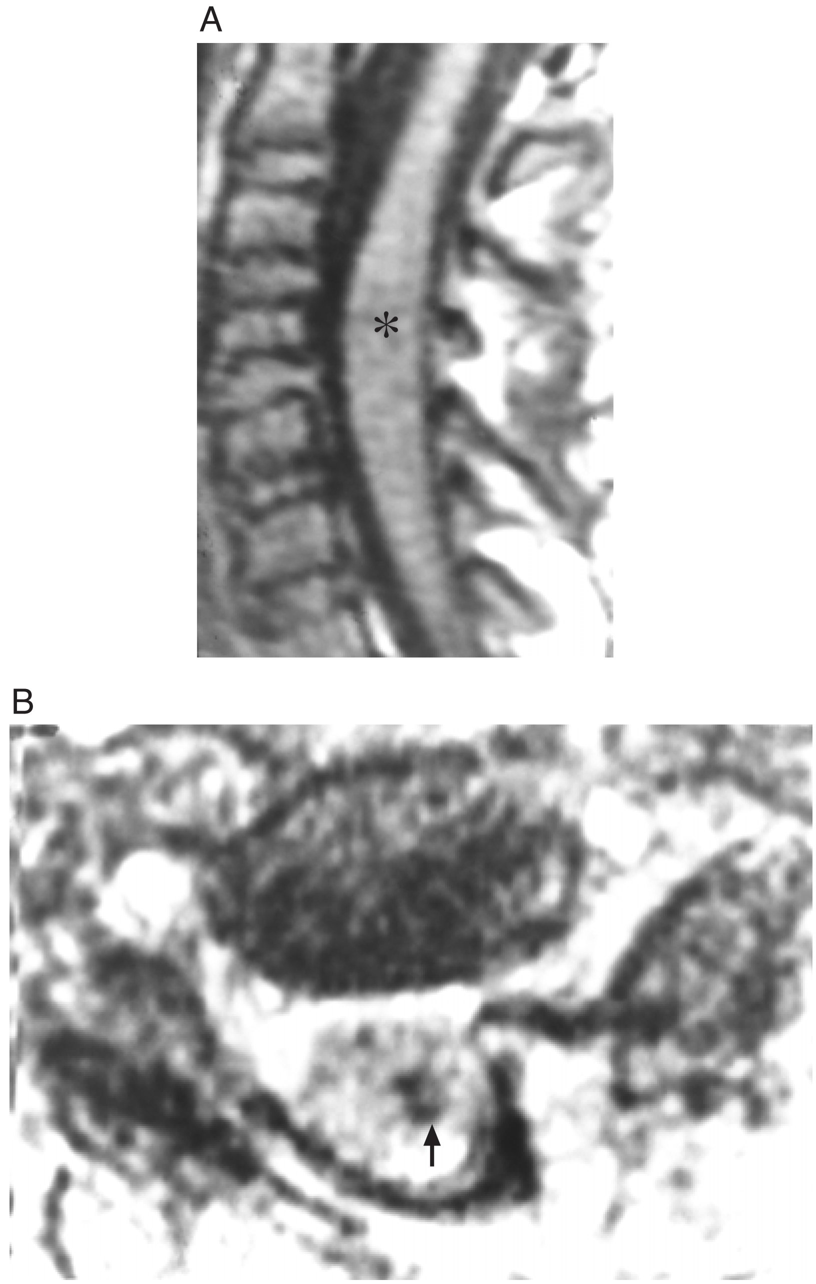

Figure A8.6.3 Hemorrhagic spinal cord contusion. (**A**) Sagittal T_1-weighted (T_R = 500 msec, T_E = 10 msec) image shows cervical spinal cord swelling (asterisk). (**B**) Transverse T_2^* gradient recalled echo (T_R = 500 msec, T_E = 15 msec, flip angle = 15°) image shows an area of focal hypointensity (arrow) indicating acute hemorrhage (deoxyhemoglobin).

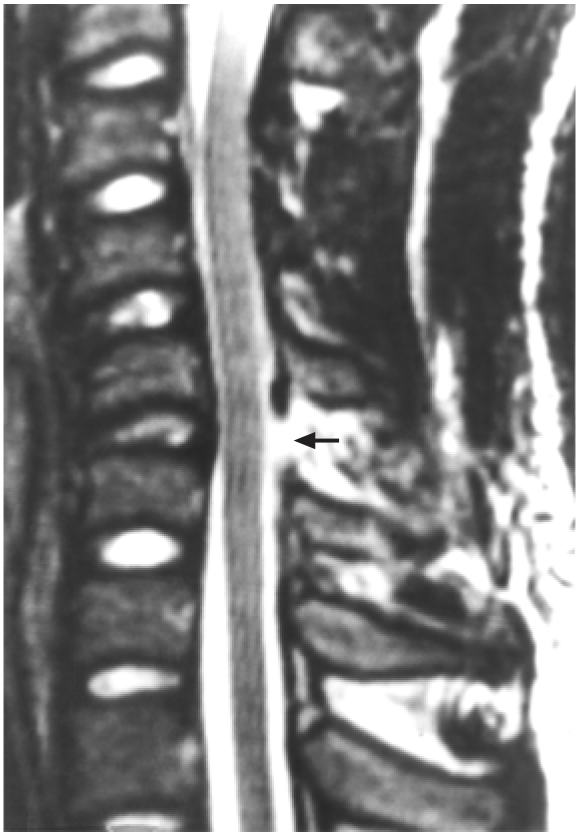

Figure A8.6.4 Traumatic spinal ligamentous injury. Sagittal T_2-weighted (T_R = 4000 msec, T_E = 100 msec) fat suppressed image shows a focal segmental dehiscence of the ligamenta flava (arrow) indicating traumatic rupture of these ligaments.

should be performed in either the acute or chronic stage of trauma in order to identify and direct treatment in patients who may benefit from intervention aimed at halting or reversing the pathological process, thereby preserving or regaining function.

Clinical Parameters and Troubleshooting

The gradient-recalled echo sequences are important to include as a part of an acute spine injury evaluation. The reason for this is that acute hemorrhage (e.g., deoxyhemoglobin) will be missed on routine fast spin echo scans (Fig. A8.6.3; Jinkins, 1998a). Similarly, spinal ligament tears will be overlooked on routine fast spin echo T_2-weighted studies, if simultaneous fat suppression is not used (Fig. A8.6.4; Jinkins, 1998b). It is important not to overlook these factors in the MRI analysis of spinal trauma.

If the patient is in an emergency situation, only run sequence 1, 2, 3, and 6.

Anticipated Results

In general, the aims of imaging in the patient with trauma include the detection of the specific structures or tissues involved, the determination of the extent of the injury, the assessment of general patient prognosis, and the enhancement of therapeutic planning. These goals are all aimed at a potentially positive affect on a patient's outcome. The results of these and other outcomes will largely define how medical care, including imaging studies, is dispensed in the future in patients with trauma; these decisions in turn will affect all those involved in the health care of these patients.

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