Herniated Intervertebral Disc

One of the most significant impacts of magnetic resonance (MR) has been its ability to exquisitely depict normal and pathologic anatomy of the spine. Direct acquisitions acquired in multiple planes, coupled with the ability to study the spine with different T_1- and T_2-weighted images, have enabled the critical assessment of the spinal column and its contents in ways not previously available to the medical imaging specialist. The development of contrast media has further extended the capabilities of MR imaging of the spine by improving its sensitivity, and sometimes its specificity, in certain categories of pathology.

CONVENTIONAL AND FAST SPIN ECHO

BASIC PROTOCOL

While certain pathologic conditions may be assessed utilizing specialized imaging acquisitions (e.g., gradient recalled echo: cervical spine), in general the normal signal characteristics of the skeletal components of the vertebral column typically are best illustrated on the basis of spin echo techniques (Karnaze et al., 1987; Modic et al., 1984; Murayama et al., 1990; Van Dyke et al., 1989; Tsruda et al., 1990). In part because of low relative water content, the intervertebral discs are normally seen to be hypointense on T_1-weighted images relative to adjacent vertebral bone marrow signal, becoming relatively hyperintense on T_2-weighted images. Upon aging, this MR signal pattern progressively changes because of disc degeneration, with the disc becoming yet more hypointense on T_1-weighted images and reversing to become hypointense on T_2-weighted images (Edelman et al., 1985; Hedberg et al., 1988; Holtas et al., 1987; Masaryk et al., 1988; Robertson et al., 1991; Ross et al., 1987).

The following sequences comprise the preferred protocol for high-field MR machines. On some machines alternate gradient recalled echo acquisitions may be more desirable. 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, or in cases of epidural masses of ambiguous etiology (e.g., epidural neoplasia/infection versus intervertebral disc fragment).

Table A8.1.1 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 (i.e., T_E) given below in subsequent tables will be varied accordingly (the smaller the gradient strength, the longer the echo time for a particular scan). See Jinkins (1993a,b), Ross et al. (1989), Wasserstrom et al. (1993), and Yamashita et al. (1994).

This entire protocol should take 35 to 45 min to complete.

Table A8.1.1 Equipment Parameters for Spine Imaging in Cases of Intervertebral Disc Disease

Coil type	Cervical, thoracic, lumbar: phased array surface coil (or other depending upon machine compatibility and availability)
Peripheral gating	Thoracic spine only (optional)
Respiratory gating	Thoracic spine only (optional)
Flow compensation pulse	Any level (optional)
Use of contrast agents	Optional (see Alternate Protocol)

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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 materials 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 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 A8.1.2 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	Laser light centered—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: 340 mm, 340 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 A8.1.2 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 A8.1.3.
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

14. Review the pilot scans and set the saturation pulse so that it is correctly placed anterior to the slab of interest.
15. Run sequence 3 according to Table A8.1.4.

Table A8.1.3 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 Lumbrosacral: 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	As many 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})	4
Flow compensation	Yes (if available)
Saturation pulses	Yes; anterior cervical/thoracic/lumbar slabs to saturate larynx/vessels/heart
Slice series	Left to right or the reverse depending on preference
Scan time	~8 min

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 A8.1.5.

Table A8.1.4 Primary Clinical Imaging Parameters for Sequence 3 (T_2-Weighted Image, FSE)[a]

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 A8.1.3)
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 A8.1.3)
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)	Table A8.1.3
Number of slices	Varies with spinal level
Slice gap	Table A8.1.3
Number of acquisitions (N_{acq})	1
Flow compensation	Yes (if available)
Saturation pulses	Yes; anterior cervical/thoracic/lumbar slabs anteriorly to saturate larynx/vessels/heart
Fat suppression	Yes
Slice series	Left to right or the reverse depending on preference
Scan time	~4 min

[a]FSE, fast spin echo.

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 A8.1.6.

20. Run sequences according to Table A8.1.6.

GRADIENT RECALLED ECHO SEQUENCES

ALTERNATE PROTOCOL 1

With some machines, or according to preferences, gradient recalled echo acquisitions may be used in the sagittal and/or transverse planes to clearly distinguish between discs and soft tissue and to clarify the spinal neural foramen in the cervical region (Murayama et al., 1990; Van Dyke et al., 1989).

Sequence 6: Sagittal gradient recalled echo

1. Run sequence 6 according to Table A8.1.7.

Sequence 7: Transverse gradient recalled echo

2. Run sequence 7 according to Table A8.1.8.

Table A8.1.5 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 A8.1.3)
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 A8.1.3)
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: 3–5 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 Basic Protocol, step 16
Saturation pulses	No
Scan time	~4 min

ALTERNATE PROTOCOL 2

CONTRAST-ENHANCED MRI ACQUISITIONS

In some situations, such where the findings of an MRI scan do not match the clinical findings, the use of intravenous (i.v.) paramagnetic contrast material may be indicated (Jinkins, 1993a,b; Ross et al., 1989; Wasserstrom et al., 1993; Yamashita et al., 1994).

Materials

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

Set up patient and equipment

1. Using the same equipment, perform patient setup as in the Basic Protocol.
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.

   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.

Perform pilot scan

3. Run a rapid three-plane positioning pilot scan (sequence 1; see Basic Protocol, step 10).

Table A8.1.6 Primary Clinical Imaging Parameters for Sequence 5 (T_2-Weighted Image, FSE)[a]

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 A8.1.3)
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 A8.1.3)
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)	As in sequence 4 (Table A8.1.5)
Number of slices	Varies with spinal level
Slice gap	As in sequence 4 (Table A8.1.5)
Number of acquisitions (N_{acq})	2
Slice locations	See Basic Protocol, step 16)
Flow compensation	Yes (if available)
Saturation pulses	No
Scan time	~4 min

[a]FSE, fast spin echo.

Table A8.1.7 Primary Clinical Imaging Parameters for Sequence 6 (T_2^* GRE)[a]

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Centered on the area of interest (as in sequence 2, Table A8.1.3)
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 A8.1.3)
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 mm
Number of slices	Varies with spinal level
Slice gap	1 mm or less
Number of acquisitions (N_{acq})	3
Flow compensation	Yes (if available)
Saturation pulses	Yes
Scan time	~6 min

[a]T_2^* GRE, T_2^* gradient recalled echo.

Table A8.1.8 Primary Clinical Imaging Parameters for Sequence 7 (T_2^* GRE)[a]

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Centered on the area of interest (as in sequence 2, Table A8.1.3)
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 A8.1.3)
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 level
Slice gap	1 mm or less
Number of acquisitions (N_{acq})	1
Slice locations	See Basic Protocol, step 16
Flow compensation	Yes (if available)
Saturation pulses	Yes
Scan time	~2 min

[a] T_2^* GRE, T_2^* gradient recalled echo.

Sequences 8 and 9: Contrast agent enhanced T_1-weighted spin echo

4. Leaving the patient in the magnet, inject the contrast agent, flush the line with 10 ml saline, and then immediately run sagittal (see Basic Protocol, steps 11 to 13; sequence 8) and transverse (see Basic Protocol, steps 16 to 18; sequence 9) T_1-weighted image sequences according to Tables A8.1.3 and A8.1.5, respectively (sequences 2 and 4 in the Basic Protocol).

An i.v. dose of 0.1 mmol/kg of contrast agent is usually given.

COMMENTARY

Background Information

The description of disc disease, above and beyond that of simple degeneration, is an area of diagnosis that suffers because of a lack of uniform terminology. To be fair; there are many reasonable terms; however, their use is irregular, overlapping and inconsistent. These terms should be chosen carefully to reflect both the pathology as well as to fit the imaging procedure. Successful, appropriate usage of terms for spinal intervertebral disc disease will benefit the radiologist, the referring clinician, and ultimately the patient. A pragmatic system should be used that attempts, above all, to define terms according to what is actually clearly observed on medical images: only three basic root terms can be used to describe annular contour changes of disc bulge, protrusion, and herniation. A *disc bulge* is broad-based in the transverse plane and may be circumferential (i.e., nondirectional), anterior, posterior, or lateral (i.e., directional). A *disc protrusion* is a focal annular contour change in the transverse plane; some authors have defined focal as less than 25% of the disc periphery. Disc protrusions may be projected into any one or more than one circumferential direction(s); when protrusions are found in more than one direction, the term "multidirectional disc protrusion" is used. A disc herniation may be transannular, transchondral, or transosseous with regard to the path of egress. A transannular *disc extrusion* is a disc fragment that has partially or completely left the confines of the intervertebral disc via the peripheral annulus fibrosus. There are three types of transannular herniations: contiguous, sequestered, and transdural.

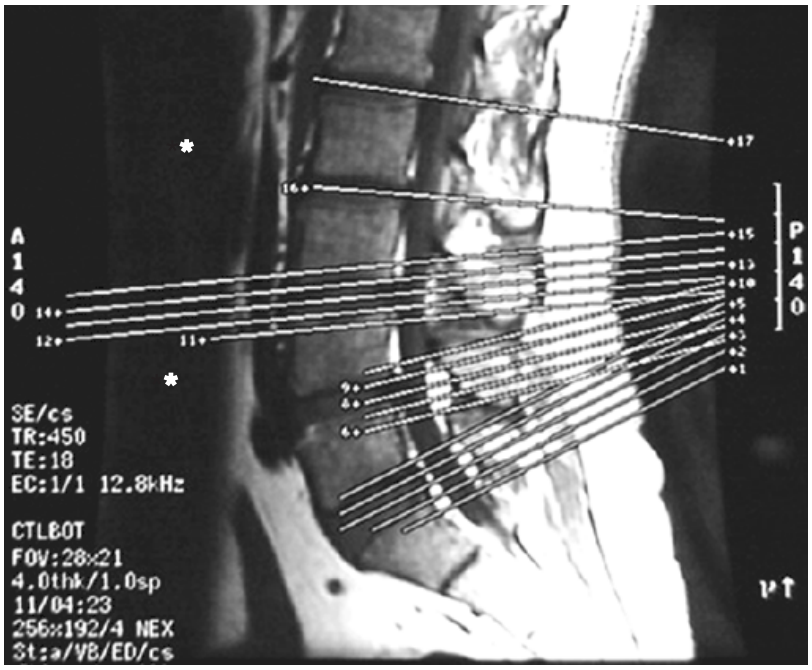

Figure A8.1.1 Sagittal section showing allocation of transverse sections from midline sagittal section of lumbosacral spine. Note the anterior spatial saturation band (asterisks).

Contiguous disc herniations are focal extradural disc masses that remain in contact with the parent disc and that have a polypoid shape on sagittal sectioning; the diameter of the polypoid disc mass is usually larger than that of the parent intervertebral disc, thus giving the abnormality its polypoid configuration. *Sequestered disc herniations* are disc fragments that have migrated epidurally, either cranially, or caudally, for a variable distance from the parent disc. *Transdural disc herniations* are rare occurrences accounting for only 0.3% of all transannular disc herniations; the lumbar area is the level most commonly affected. They are believed to be caused by preceding epidural scarring (e.g., prior surgery, earlier disc extrusion, previous trauma) resulting in dural adhesions that promote rupture of the extruded disc directly into the thecal sac through a tear in the dura/arachnoid matter. In addition to the transannular route of disc herniation, herniations may enter into or through the cartilaginous vertebral end plate or through the vertebral body itself: a *transchondral disc herniation* is also termed a Schmod node; a *transosseous disc herniation* is also called a limbus vertebra. Note that the simple, unmodified term *disc herniation* can be an imprecise, nebulous term that has many varying meanings to too many physicians (Taveras, 1989). Therefore it can be misleading. Barring internal derangement reaching the disc surface (i.e., annular tears), the broad set of terms defined here specifically describe virtually every pathologic condition involving the borders of the intervertebral disc.

Critical Parameters and Troubleshooting

Cerebrospinal fluid (CSF) flow, cardiac, laryngeal, body wall and other sources of motion can produce artifacts that can on occasion significantly degrade the images. Proper spatial (e.g., prevertebral) saturation pulses and sometimes flow compensation pulses and/or cardiac/respiratory gating can reduce these artifacts significantly. In many instances, these artifacts may be difficult or impossible to overcome from patient to patient.

Anticipated Results

The goal of studying the intervertebral disc is to diagnose clinically relevant disease of this structure. While the terminology is at present somewhat ambiguous from one medical center to another and from physician to physician, the images obtained utilizing these MRI sequences will nevertheless yield reproducible results enabling reliable visualization of disc pathology. Some examples are shown in Figure A8.1.1 and Figure A8.1.2.

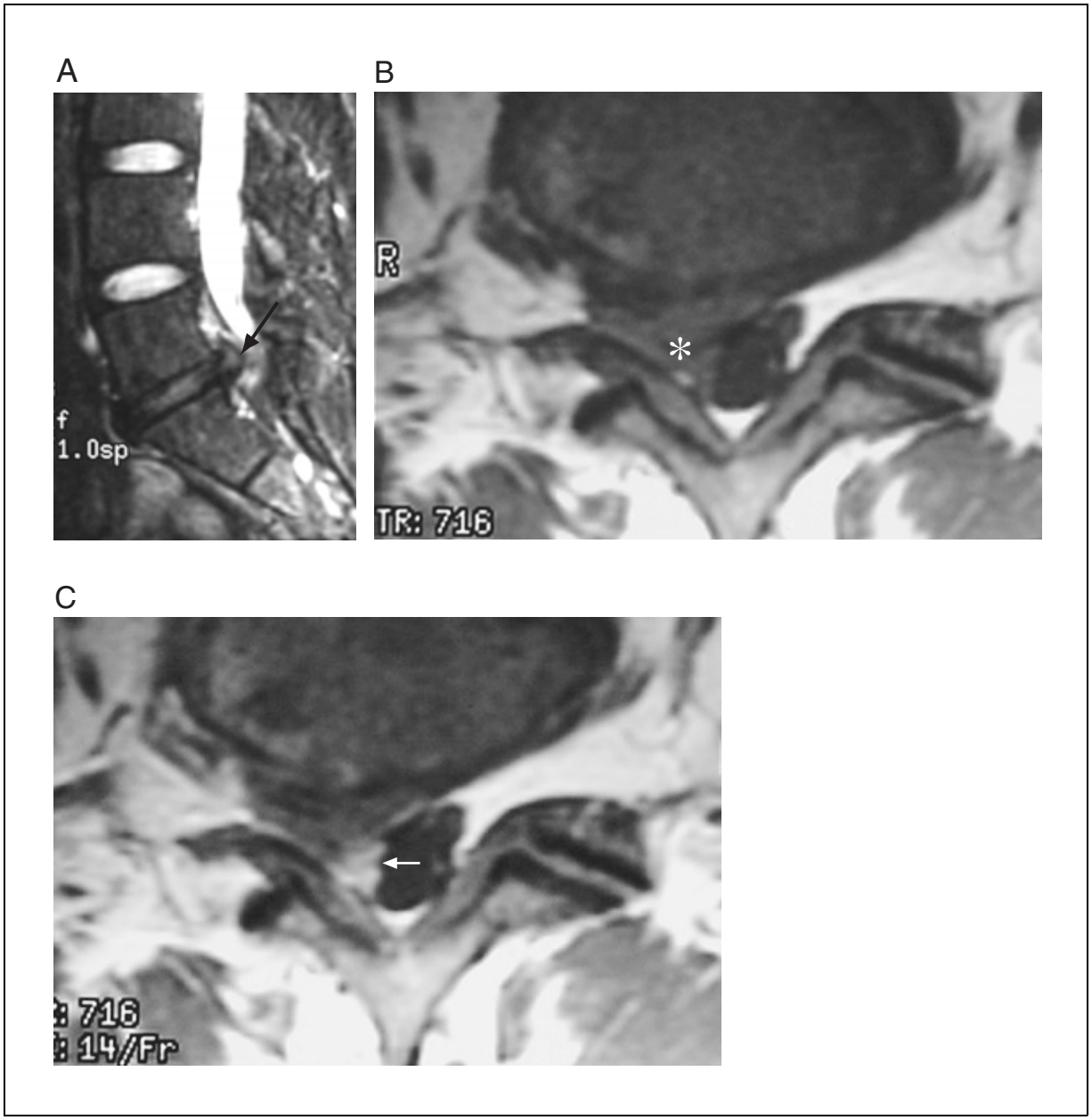

Figure A8.1.2 Intervertebral disc herniation associated with enhancing radiculitis. (**A**) Sagittal T_2-weighted (T_R = 4000 msec, T_E = 90 msec) section shows a large L5-S1 posterior intervertebral disc herniation (arrow). (**B**) Transverse T_1-weighted (T_R = 500 msec, T_E = 10 msec) section at L5-S1 shows the disc herniation (asterisk) extending toward the right side. (**C**) Intravenous gadolinium–enhanced transverse T_1-weighted (T_R = 500 msec, T_E = 10 msec) section at L5-S1 shows several enhancing nerve roots (arrow) intrathecally.

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