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Abnormal Magnetic-Resonance Scans of the Cervical Spine in Asymptomatic Subjects

A Prospective Investigation*†

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ABSTRACT: **Previous investigations with plain radiography, myelography, and computed tomography have shown that degenerative disease of the cervical spine frequently occurs in the absence of clinical symptoms. We studied the magnetic resonance-imaging scans of sixty-three volunteers who had no history of symptoms indicative of cervical disease. The scans were mixed randomly with thirty-seven scans of patients who had a symptomatic lesion of the cervical spine, and all of the scans were interpreted independently by three neuroradiologists. The scans were interpreted as demonstrating an abnormality in 19 per cent of the asymptomatic subjects: 14 per cent of those who were less than forty years old and 28 per cent of those who were older than forty. Of the subjects who were less than forty, 10 per cent had a herniated nucleus pulposus and 4 per cent had foraminal stenosis. Of the subjects who were older than forty, 5 per cent had a herniated nucleus pulposus; 3 per cent, bulging of the disc; and 20 per cent, foraminal stenosis. Narrowing of a disc space, degeneration of a disc, spurs, or compression of the cord were also recorded. The disc was degenerated or narrowed at one level or more in 25 per cent of the subjects who were less than forty years old and in almost 60 per cent of those who were older than forty.**

The prevalence of abnormal magnetic-resonance images of the cervical spine as related to age in asymptomatic individuals emphasizes the dangers of predicating operative decisions on diagnostic tests without precisely matching those findings with clinical signs and symptoms.

The decision to operate on many patients who have a symptomatic cervical lesion has traditionally depended on the correlation of the mechanical origin of neurogenic symptoms with abnormalities seen on imaging with contrast medium. Until recently, plain radiography, myelography, and computerized tomography, alone or in combination, have been utilized, but now the use of magnetic resonance imaging is increasing. This is an attractive diagnostic alternative because it is non-invasive, involves no radiation, is not known to be associated with any side effects, and provides superior resolution of the anatomy of soft-tissue structures.

Excellent sensitivity (a low prevalence of false-negative findings) has been reported for magnetic resonance imaging in the identification of neural compression by mechanical lesions in the cervical and lumbar spine[3,4,7,9,10]. However, the important issue of specificity (the prevalence of false-positive findings) needs clarification. Recently, in an investigation of the lumbar spine in asymptomatic subjects, we found a major abnormality on the magnetic resonance images of 22 per cent of the subjects who were less than forty years old and 57 per cent of those who were more than forty[1]. To our knowledge, no analogous studies have been done on the cervical spine. The purpose of this report was to document the prevalence of clinically false-positive interpretations of magnetic resonance scans of the cervical spine in an asymptomatic control population. Abnormal interpretations were defined as falsely positive if the subject had no symptoms or signs.

Materials and Methods

A full magnetic-resonance scan of the cervical spine was made for sixty-three volunteer subjects. They ranged in age from twenty to seventy-three years (average, forty years). The normal subjects were solicited by advertisements and calls for volunteers for a study on an unspecified topic. The respondents were then screened, as was described, and, when possible, we included the spouses of the subjects to balance the distribution of age and sex. There were twenty-five men and thirty women. Subjects were screened prospectively with a standardized questionnaire and with personal interviews, and only those who had no history of cervical pain or trauma, pain in the shoulder, or radicular symptoms referable to the cervical nerve-roots were included in the study.

Multiplane magnetic-resonance scans of the cervical spine were made with a 1.5-tesla imaging system (Signa;

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TABLE I

DIAGNOSIS, AS DETERMINED BY MAGNETIC RESONANCE IMAGING, CLASSIFIED BY AGE IN SIXTY-THREE ASYMPTOMATIC SUBJECTS*

	<40 Yrs. Old (N = 40)	>40 Yrs. Old (N = 23)	Total (N = 63)
Herniated disc	4 (10%)	1 (5%)	5 (8%)
Bulging disc	0	1 (3%)	1 (2%)
Foraminal stenosis	1 (4%)	5 (20%)	6 (9%)

* The abnormality was graded as major for at least one disc level.

General Electric, Milwaukee, Wisconsin) and a circular surface coil. First, a sagittal localizing series was performed with a repetition time of 400 milliseconds, an echo time of twenty milliseconds, a slice thickness of five millimeters and a one-millimeter interslice gap, a twenty-four-centimeter field of view, a 256-by-128 matrix, and one excitation (scan time, fifty-six seconds). Next, T1-weighted sagittal images were made with a repetition time of 600 milliseconds, an echo time of thirty milliseconds, a slice thickness of three millimeters and a one-millimeter interslice gap, a twenty-four-centimeter field of view, a 256-by-192 matrix, and four excitations (scan time, seven minutes and forty-four seconds). Gradient echo imaging was then used to generate T2*-weighted images (not so-called pure T2-weighted images, but close to it, using gradient echo rather than spin echo technique) with a repetition time of fifty milliseconds, an echo time of thirteen milliseconds, a flip angle of 6 degrees, a slice thickness of five millimeters and no gap, a twenty-four-centimeter field of view, a matrix of 256 by 128, and eight excitations (scan time, four minutes and seventeen seconds). Axial T2*-weighted images were obtained with a repetition time of thirty-five milliseconds, an echo time of fifteen milliseconds, a flip angle of 5 degrees, a slice thickness of two millimeters and no gap, a twenty-centimeter field of view, a matrix of 256 by 128, and two excitations (scan time, nine minutes and thirty-four seconds; additional reconstruction time, four minutes).

The sixty-three studies of the asymptomatic volunteer subjects were mixed randomly with thirty-seven scans, made with the same protocol and the same scanner, of patients who had an unequivocal abnormality (either a herniated nucleus pulposus or foraminal stenosis) and who had well defined clinical symptoms or signs that were associated with the abnormality. The 100 scans were presented separately, in a randomized sequence, to three independent neuroradiologists who had no knowledge of the identity of the subject or patient. Each neuroradiologist graded each disc level (from the second cervical level to the first thoracic level) for the presence and severity of spurs, narrowing of the disc space, degeneration of the disc, herniated nucleus pulposus, bulging of the disc, foraminal stenosis, and impingement or compression of the cord.

A forced-choice grading sheet was used, with the severity of each abnormal finding being rated as mild, moderate-no (not important), moderate-yes (important), or severe. Due to limited space on the film, axial images of the disc space between the seventh cervical and the first thoracic vertebrae were not evaluated in twenty patients.

Since precise definitions of some lesions of cervical discs vary among radiologists, there was a spectrum of interpretations from the three independent neuroradiologists, all of whom were experienced in magnetic resonance imaging of the cervical spine. Precise definitions were not agreed on before the grading, but general guidelines were established. Disc-space narrowing was considered to be a loss of height relative to the cephalad disc space. It was graded as mild if less than 25 per cent of the height had been lost, moderate-no if the loss was 25 to 50 per cent, moderate-yes if it was 50 to 75 per cent, and severe if it was 75 per cent or more. Degeneration of the disc was usually seen in conjunction with loss of height, and it was characterized by a decreased signal in the disc on the T2*-weighted images.

Herniated nucleus pulposus was considered to be an extrusion, mainly focal, beyond the osseous confines of the vertebral body, of tissue in which the signal was of intermediate intensity (on the T1-weighted image) and high in-

TABLE II

NUMBER OF INVOLVED DISC LEVELS DEMONSTRATED BY MAGNETIC RESONANCE IMAGING IN SIXTY-THREE ASYMPTOMATIC SUBJECTS*

	<40 Yrs. Old (N = 167)		>40 Yrs. Old (N = 97)		
	Major Abnormality	Minor Abnormality†	Major Abnormality	Minor Abnormality†	Significant‡
Herniated disc	5 (3%)	7 (4%)	1 (1%)	4 (4%)	
Bulging disc	0	8 (5%)	1 (1%)	5 (5%)	
Foraminal stenosis	5 (3%)	7 (4%)	9 (9%)	14 (14%)	Yes
Disc-space narrowing	3 (2%)	18 (11%)	15 (16%)	21 (22%)	Yes
Degenerated disc	13 (8%)	NA	36 (37%)	NA	Yes
Spurs (spondylosis)	5 (3%)	23 (14%)	6 (6%)	33 (34%)	Yes
Abnormal cord§	15 (9%)	15 (9%)	1 (1%)	17 (18%)	

* The average of the independent determinations by the three neuroradiologists.
† NA = not available.
‡ Difference in the incidences of the finding between the two age-groups. Significant at $p < 0.05$, as determined by chi-square analysis.
§ The abnormality was considered minor if there was impingement or remodeling and as major if there was compression with loss of posterior subarachnoid space.

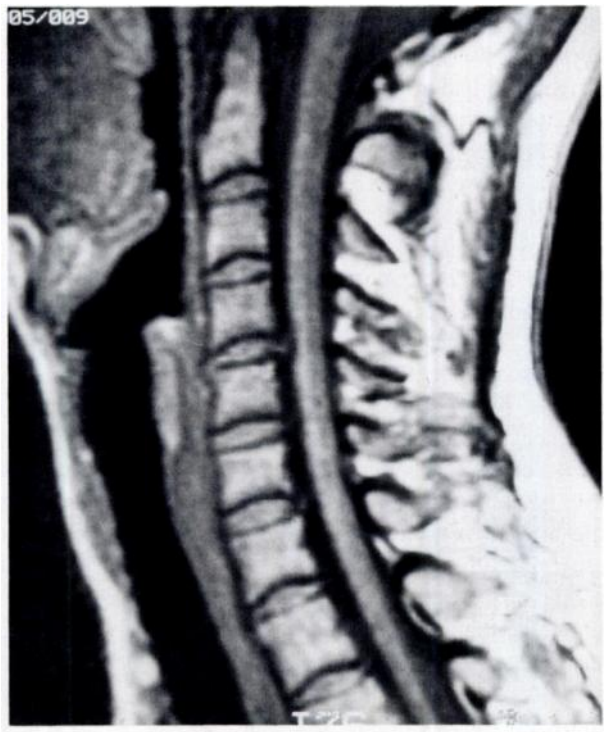

FIG. 1-A

Figs. 1-A, 1-B, and 1-C: Scans of the cervical spine in an asymptomatic thirty-four-year-old woman.

Fig. 1-A: T1-weighted sagittal sequence showing a moderately herniated nucleus pulposus between the fourth and fifth cervical vertebrae and mild herniations between the fifth and sixth and the sixth and seventh cervical vertebrae.

tensity (on the T2*-weighted image). Bulging of a disc was defined as a small, diffuse, non-focal protrusion of non-osseous material beyond the normal disc space. The changes in the spinal cord were defined as impingement or remodeling when the cord was flattened slightly and diffusely or was reshaped eccentrically without obliteration of the posterior subarachnoid space. In contrast, compression of the cord was defined as the presence of a large, concave defect in the cord associated with obliteration of the anterior and posterior subarachnoid spaces.

The score from each neuroradiologist for each finding at a given level was converted to a binary notation: major versus minor (that is, severe or moderate-yes versus moderate-no, mild, or none). The results from each of the three readers were averaged and then were tabulated according to the age of the patient, the type of abnormality, and the severity of the findings. Only the abnormalities that were classified as major were included in the final tabulation of important abnormalities. The consistency of the interpretations among the three neuroradiologists was also assessed. Finally, the percentage of asymptomatic subjects who were seen to have major abnormalities on the magnetic resonance scans of the cervical spine was calculated to establish the prevalence of clinically false-positive scans.

The predictive power of the prevalence of abnormal magnetic-resonance scans was estimated by calculation of the 95 per cent confidence interval by the method of normal approximation to the binomial. Differences in the prevalence of the various abnormalities in the two age-groups were tested for significance with a chi-square test. When the p value was less than 0.05, the difference was considered statistically significant.

Results

On the average, the three neuroradiologists independently interpreted the magnetic resonance scans as showing a major abnormality in 19 per cent of the sixty-three asymptomatic subjects (95 per cent confidence interval, 10 to 28

FIG. 1-B

FIG. 1-C

Fig. 1-B: T2*-weighted axial sequence showing a posterior herniation with impingement on the cord at the fourth and fifth cervical vertebrae.

Fig. 1-C: T2*-weighted axial sequence showing a moderate central-left posterior herniation with impingement of the cord at the fifth and sixth cervical vertebrae.

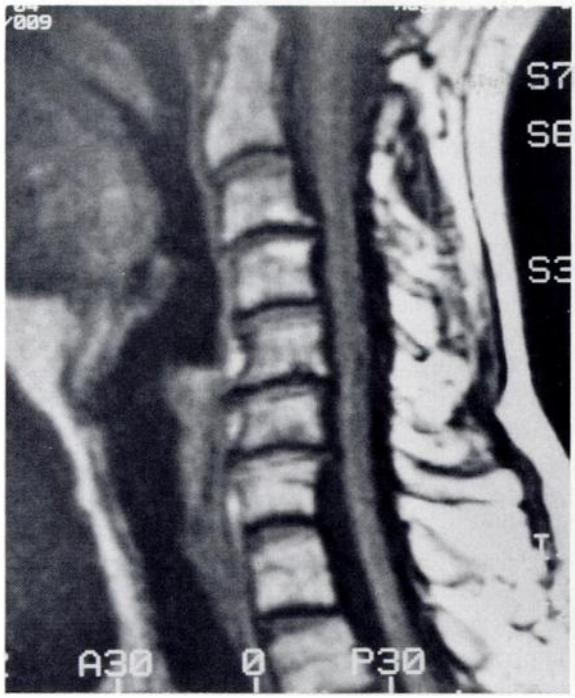

FIG. 2-A

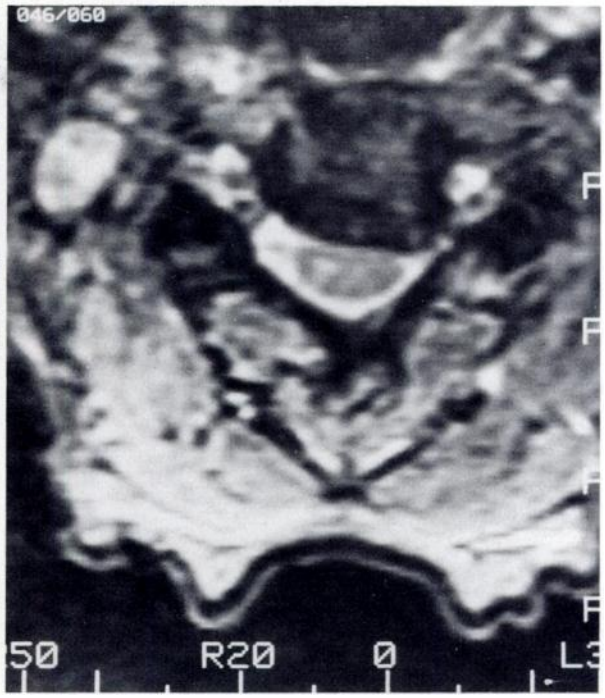

FIG. 2-B

Figs. 2-A and 2-B: Scans of the cervical spine in an asymptomatic sixty-three-year-old woman.
Fig. 2-A: T1-weighted sagittal sequence demonstrating posterior spurs between the third and fourth and the fifth and sixth cervical vertebrae and mild herniation of the nucleus pulposus between the sixth and seventh cervical vertebrae.
Fig. 2-B: T2*-weighted axial sequence showing severe foraminal stenosis on the left between the third and fourth cervical vertebrae.

per cent). The prevalence of abnormal findings was similar in the men and women, but the prevalence of several of the findings varied according to age. The scans showed a major abnormality in an average of 14 per cent of the subjects who were less than forty years old (95 per cent confidence interval, 4 to 24 per cent) and in an average of 28 per cent of those who were more than forty (95 per cent confidence interval, 10 to 46 per cent) ($p < 0.05$). The level that was most frequently considered to be abnormal was between the fifth and sixth cervical vertebrae, followed in frequency by that between the sixth and seventh cervical vertebrae and that between the fourth and fifth cervical vertebrae.

The most frequently seen abnormalities in the asymptomatic subjects that might be associated with clinical importance were herniated nucleus pulposus and foraminal stenosis (8 and 9 per cent, respectively). Bulging of the disc was seen in only one of the sixty-three asymptomatic subjects (Table I). Some of the subjects, levels, and findings were not included in the calculations because at least two of the readers rated the severity of a finding as minor. The numbers of disc levels at which major and minor abnormalities were seen are shown in Table II.

We also determined the prevalences of abnormalities for which the clinical relevance is less well understood. The prevalence of at least one narrowed disc space or degenerated disc was 25 per cent in the forty subjects who were less than forty years old (Figs. 1-A, 1-B, and 1-C) and 57 per cent in the twenty-three subjects who were older than forty ($p < 0.01$). To a lesser degree, the incidence of spurs and foraminal stenosis (Figs. 2-A and 2-B) was also higher in the older age-group. In contrast, neither herniation nor bulging of the disc was observed more frequently in the older subjects.

Figures 1-A through 3-C illustrate the range of abnormal findings in the asymptomatic subjects.

The interpretations of the thirty-seven positive scans of the patients who had symptoms showed a 99 per cent correlation among the three readers. No scans were falsely negative. Usually, when there was a disagreement in interpretation, it involved a slight variation in the rating of the severity of a finding rather than a difference of opinion as to whether or not the finding was present. The readers were considered to be in complete agreement when they were within one severity rating of each other, as long as the difference did not mean that one rating listed a finding as major and the other, as minor. A partial disagreement was considered to be a difference of two severity ratings, or of one rating if the difference was between the minor and the major categories. A complete disagreement was considered to be a difference of more than two severity ratings or the diagnosis of a different abnormality (for example, if one reader recorded spurs and the other, herniated nucleus pulposus).

One hundred and eighty disc levels were evaluated in the symptomatic patients, and there was complete agreement by all three neuroradiologists about the exact diagnosis at 71 per cent of the levels, complete agreement by all three readers or partial disagreement by one reader about the diagnosis at 89 per cent, and complete agreement by at least two readers about the diagnosis at 98 per cent. Two hundred

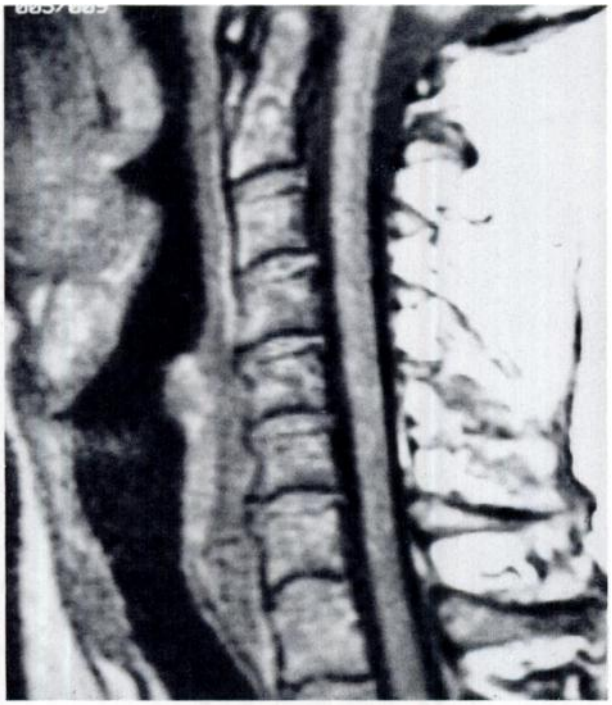

FIG. 3-A

Figs. 3-A, 3-B, and 3-C: Scans of the cervical spine in an asymptomatic forty-one-year-old man.

Fig. 3-A: T1-weighted sagittal sequence showing mild posterior herniation of the nucleus pulposus between the third and fourth, the fourth and fifth, the fifth and sixth, and the sixth and seventh cervical vertebrae.

and ninety-five disc levels were evaluated in the asymptomatic subjects, and there was complete agreement by all three neuroradiologists about the diagnosis at 83 per cent of the levels, complete agreement by all three readers or partial disagreement by one reader about the diagnosis at 95 per cent, and complete agreement by at least two readers about the diagnosis at 99 per cent. Again, the disagreement was generally not about the presence or absence of an abnormality but concerned the precise scoring of its severity.

Discussion

Most imaging studies of the spine, and especially magnetic resonance imaging, can demonstrate detailed anatomy and pathological changes but cannot directly reveal their clinical significance. To determine the importance of abnormalities on magnetic resonance images, one must take into account the frequency and spectrum of structural abnormalities that may not cause symptoms.

To evaluate the clinical value of any diagnostic study, one must know the sensitivity of the test — that is, the prevalence of false-negative findings. Several studies of the lumbar spine have shown the sensitivity of magnetic resonance imaging to be equivalent or superior to that of computed tomography, myelography, and discography for the diagnosis of herniated nucleus pulposus and spinal stenosis[4,7,8,11]. Magnetic resonance imaging is also sensitive enough to detect a partial or complete tear of the anulus fibrosus, which cannot be seen with the other non-invasive imaging modalities[14].

The frequency with which magnetic resonance imaging reveals abnormalities, and what types of abnormalities it reveals, in the absence of clinical findings, still must be determined. Most often, specificity is measured in symptomatic patients, but the rate of false-positive findings is often much higher when asymptomatic subjects are studied, regardless of the imaging modality under consideration. For example, studies of the lumbar spine have demonstrated a high incidence of abnormal myelograms (24 per cent), computed tomography scans (36 per cent), and magnetic resonance scans (28 per cent) in asymptomatic subjects[1,5,13]. However, the differences in the rates of false-positive findings in asymptomatic subjects, compared with those in pa-

FIG. 3-B

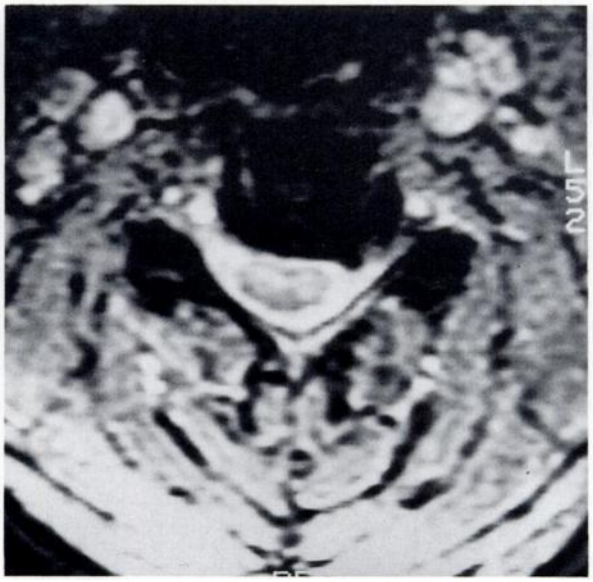

FIG. 3-C

Fig. 3-B: T2*-weighted axial sequence demonstrating foraminal stenosis bilaterally between the sixth and seventh cervical vertebrae.

Fig. 3-C: T2*-weighted axial image revealing foraminal stenosis on the left side between the fourth and fifth cervical vertebrae.

tients for whom operative confirmation was the standard for true-positive correlation, may not be accurate. Operative confirmation of an abnormality that was seen on radiographs does not necessarily mean that the symptoms were caused by that abnormality. In addition, operatively treated patients are a pre-selected group, from which patients who had no abnormalities or who had equivocal abnormalities on imaging studies were excluded.

The finding of major abnormalities on the magnetic resonance scans of 19 per cent of the sixty-three asymptomatic subjects in our study is comparable with the 21 per cent incidence of filling defects that Hitselberger and Witten observed on cervical myelograms of asymptomatic subjects. Teresi et al. analyzed magnetic resonance scans of the cervical spine for evaluation of lesions in the larynx, and they observed a herniated nucleus pulposus or a bulge of one or more discs in 20 to 57 per cent of the patients. However, that study was performed with a 0.3-tesla magnet, only T1-weighted sequences were done, and the scans were interpreted in a cooperative manner by a group. The lack of T2-weighted images was a serious deficiency of the study. It precluded accurate detection of early degeneration of discs, may have failed to reveal a protrusion of degenerated disc material, and made detection of spondylosis difficult because of the lack of contrast between bone and cerebrospinal fluid[6].

Although the differences in the age distribution of our subjects and those of Teresi et al. preclude an exact comparison between the prevalences of some of the lesions (for example, spurs, narrowing of the disc space, and impingement or compression of the cord), our findings were similar in that the prevalences increased with increasing age. However, the prevalence of herniated nucleus pulposus or bulging of the disc in our study did not increase with age. This difference may be due, in part, to the grading, in our protocol, of the severity of the findings on the magnetic resonance scans. Except for the grading of compression of the cord, Teresi et al. did not specifically evaluate severity; they recorded only the presence or absence of an abnormality.

In our analogous investigation[1] of magnetic resonance scans of the lumbar spine, the prevalence of abnormal findings was lower than that in the present study of the cervical spine. Herniated nucleus pulposus was observed in 24 per cent of the asymptomatic subjects in the previous study, compared with only 8 per cent in the present study. The spinal cord is under tighter space constraints in the cervical region than the cauda equina is in the lumbar region, and therefore it seems less likely that major lesions of the cervical spine will occur in the absence of symptoms. Degeneration of the disc at one level or more was seen in 37 per cent of the cervical spines and in 55 per cent of the lumbar spines.

There was substantial agreement between readers in both this study and our earlier investigation[1], but the rate of agreement was slightly lower for the scans of the cervical spine than for those of the lumbar spine. This difference most likely reflects a greater degree of controversy about the anatomical definitions of what constitutes a radiographic abnormality in the cervical spine.

When the reliability of our data is analyzed, it is important that two essential elements be considered: the selection of subjects and the design of the study. The demographic characteristics of the asymptomatic subjects were similar to those of a typical spectrum of patients who have symptoms referable to lesions of the cervical spine.

Possibly, a lesion that is revealed by a magnetic resonance scan may not produce symptoms initially but may do so later. Ideally, the asymptomatic subjects should be followed for many years to determine how often that occurs, but such a possibility does not justify prophylactic measures. It should also be emphasized that magnetic resonance accurately images the anatomy, and many abnormal findings in asymptomatic individuals represent what we term clinical false-positive results and are not true anatomical false-positive results.

In conclusion, our finding of major abnormalities on the magnetic resonance scans of the cervical spine of 19 per cent of the sixty-three asymptomatic subjects suggests that such findings on this highly sensitive scan must be strictly matched with clinical signs and symptoms before therapy is instituted. The rate of false-positive findings (abnormalities in the absence of symptoms) was comparable with that for myelography in the study by Hitselberger and Witten, but it was lower than the rate in our previous study of magnetic resonance imaging of the lumbar spine[1]. The prevalence of narrowing or degeneration of one or more disc-spaces and of spondylosis was high and increased with age. This observation confirms *in vivo* what has been evident in autopsy studies[2] and suggests that such lesions are part of the normal, or at least common, aging process of spinal degeneration.

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References

1. BODEN, S. D.; DAVIS, D. O.; DINA, T. S.; PATRONAS, N. J.; and WIESEL, S. W.: Abnormal Magnetic-Resonance Scans of the Lumbar Spine in Asymptomatic Subjects. A Prospective Investigation. J. Bone and Joint Surg., **72-A:** 403-408, March 1990.
2. DEPALMA, A. F., and ROTHMAN, R. H.: The Intervertebral Disc, pp. 30-57, Philadelphia, W. B. Saunders, 1970.
3. FLANNIGAN, B. D.; LUFKIN, R. B.; MCGLADE, CHARLES; WINTER, JAMES; BATZDORF, ULRICH; WILSON, GABRIEL; RAUSCHNING, WOLFGANG; and BRADLEY, W. G.: MR Imaging of the Cervical Spine: Neurovascular Anatomy. Am. J. Neuroradiol., **8:** 27-32, 1987.
4. GIBSON, M. J.; BUCKLEY, J.; MAWHINNEY, R.; MULHOLLAND, R. C.; and WORTHINGTON, B. S.: Magnetic Resonance Imaging and Discography in the Diagnosis of Disc Degeneration. A Comparative Study of 50 Discs. J. Bone and Joint Surg., **68-B(3):** 369-373, 1986.
5. HITSELBERGER, W. F., and WITTEN, R. M.: Abnormal Myelograms in Asymptomatic Patients. J. Neurosurg., **28:** 204-206, 1968.
6. LEE, S. H.; COLEMAN, P. E.; and HAHN, F. J.: Magnetic Resonance Imaging of Degenerative Disc Disease of the Spine. Radiol. Clin. North America, **26:** 949-964, 1988.
7. MARAVILLA, K. R.; LESH, PHILIP; WEINREB, J. C.; SELBY, D. K.; and MOONEY, VERT: Magnetic Resonance Imaging of the Lumbar Spine with CT Correlation. Am. J. Neuroradiol., **6:** 237-245, 1985.

8. MASARYK, T. J.; ROSS, J. S.; MODIC, M. T.; BOUMPHREY, FRANCIS; BOHLMAN, HENRY; and WILBER, GEOFFREY: High-Resolution MR Imaging of Sequestered Lumbar Intervertebral Disks. Am. J. Neuroradiol., **9:** 351-358, 1988.
9. MODIC, M. T.; MASARYK, THOMAS; BOUMPHREY, FRANCIS; GOORMASTIC, MARLENE; and BELL, GORDON: Lumbar Herniated Disc Disease and Canal Stenosis: Prospective Evaluation by Surface Coil MR, CT, and Myelography. Am. J. Neuroradiol., **7:** 709-717, 1986.
10. MODIC, M. T.; MASARYK, T. J.; MULOPULOS, G. P.; BUNDSCHUH, CARL; HAN, J. S.; and BOHLMAN, HENRY: Cervical Radiculopathy: Prospective Evaluation with Surface Coil MR Imaging, CT with Metrizamide, and Metrizamide Myelography. Radiology, **161:** 753-759, 1986.
11. OSBORN, A. G.; HOOD, R. S.; SHERRY, R. G.; SMOKER, W. R. K.; and HARNSBERGER, H. R.: CT/MR Spectrum of Far Lateral and Anterior Lumbosacral Disk Herniations. Am. J. Neuroradiol., **9:** 775-778, 1988.
12. TERESI, L. M.; LUFKIN, R. B.; REICHER, M. A.; MOFFIT, B. J.; VINUELA, F. V.; WILSON, G. M.; BENTSON, J. R.; and HANAFEE, W. N.: Asymptomatic Degenerative Disk Disease and Spondylosis of the Cervical Spine: MR Imaging. Radiology, **164:** 83-88, 1987.
13. WIESEL, S. W.; TSOURMAS, NICHOLAS; FEFFER, H. L.; CITRIN, C. M.; and PATRONAS, NICHOLAS: A Study of Computer-Assisted Tomography. I. The Incidence of Positive CAT Scans in an Asymptomatic Group of Patients. Spine, **9:** 549-551, 1984.
14. YU, SHIWEI; SETHER, L. A.; HO, P. S. P.; WAGNER, MARVIN; and HAUGHTON, V. M.: Tears of the Anulus Fibrosus: Correlation between MR and Pathologic Findings in Cadavers. Am. J. Neuroradiol., **9:** 367-370, 1988.