

Orientation of the Lumbar Facet Joints: Association with Degenerative Disc Disease*

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ABSTRACT: The orientation of the lumbar facet joints was studied with magnetic resonance imaging in 140 subjects to determine if there is an association between facet tropism and intervertebral disc disease or between the orientation of the facet joints and degenerative spondylolisthesis. The 140 subjects were divided into four groups: sixty-seven asymptomatic volunteers, forty-six of whom did not have a herniated disc on magnetic resonance scans (Group I) and twenty-one who did (Group II); forty-six symptomatic patients who had a herniated disc confirmed operatively (Group III); and twenty-seven patients who had degenerative spondylolisthesis at the interspace between the fourth and fifth lumbar vertebrae (Group IV).

Axial scans were made at each lumbar level and digitized, and the facet joint angle was measured by two independent observers with use of image analysis software in a personal computer. The technique of measurement of the facet angles on magnetic resonance scans was validated with a subset of subjects who also had computed tomography scans made. Similar values were obtained with the two methods ($r = 0.92$; $p = 0.00001$).

For the forty-six asymptomatic volunteers who did not have a herniated disc on the magnetic resonance scans (Group I), the median facet tropism was 5 to 6 degrees and was more than 10 degrees in 24 per cent (eleven) of the subjects. There was no association between increased facet tropism and disc degeneration. At the level of the fourth and fifth lumbar vertebrae, the median facet tropism was 10.3 degrees in the symptomatic patients who had a herniated disc at the same level and 5.4 degrees in the asymptomatic volunteers (Group I) ($p = 0.05$).

The mean orientation of the lumbar facet angles

relative to the coronal plane was more sagittal at all levels in the patients who had degenerative spondylolisthesis. The greatest difference was at the level of the fourth and fifth lumbar vertebrae ($p = 0.000001$). The mean facet angle was 41 degrees (95 per cent confidence interval, 37.6 to 44.6 degrees) in the asymptomatic volunteers and 60 degrees (95 per cent confidence interval, 52.7 to 67.1 degrees) in the patients who had degenerative spondylolisthesis. Furthermore, both the left and the right facet joints were more sagittally oriented in the patients who had degenerative spondylolisthesis. An individual in whom both facet-joint angles at the level of the fourth and fifth lumbar vertebrae were more than 45 degrees relative to the coronal plane was twenty-five times more likely to have degenerative spondylolisthesis (95 per cent confidence interval, seven to ninety-eight times). The increase in facet angles at levels other than that of the spondylolisthesis suggests that increased facet angles represent variations in anatomy rather than a secondary result of spondylolisthesis.

Facet tropism is defined as asymmetry between the left and right vertebral (apophyseal) facet-joint angles, with one joint having a more sagittal orientation than the other⁵. For years, it was postulated that this could result in intervertebral disc degeneration and herniation^{3,7,8,11,15,20}. Several studies have yielded conflicting results concerning the association between facet tropism and intervertebral disc disease^{1,2,6,10,18}. Others have suggested an association between sagittal orientation of the facet and degenerative spondylolisthesis^{9,17}. However, all of these studies have lacked true normal controls and included patients who had low-back pain or included uninvolved disc levels in the same group as the controls.

With the advent of magnetic resonance imaging, it is now possible to obtain data on tropism of facet joints and facet joint angles in clinically asymptomatic volunteers without the risk of ionizing radiation. The goals of the present investigation were to develop and validate a technique for measuring the orientation of the lumbar facet joints on magnetic resonance scans, to define facet tropism and orientation of the facet joints in an asymptomatic population who did not have herniated discs

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TABLE I
DATA ON THE ENTIRE STUDY POPULATION

Individuals	No.	Mean Age* (Yrs.)
Asymptomatic	67	42 (20-79)
Disc herniation on MRI†		
No (Group I)	46	41
Yes (Group II)	21	40
Symptomatic disc herniation (Group III)	46	41 (26-63)
Degenerative spondylolisthesis (Group IV)	27	72 (49-84)
Total	140	—

*The range is given in parentheses.

†MRI = magnetic resonance image.

evident on magnetic resonance scans, to examine the association between facet tropism and disc degeneration as well as disc herniation, and to determine the relationship between increased sagittal orientation of the facet joint and degenerative spondylolisthesis.

Materials and Methods

The material for this study consisted of magnetic resonance scans of the lumbar spines of 140 subjects: sixty-seven asymptomatic volunteers, forty-six patients who had operatively confirmed herniation of a disc, and twenty-seven patients who had degenerative spondylolisthesis at the level of the fourth and fifth lumbar vertebrae (Table I). The asymptomatic volunteers were screened to eliminate those who had a history of low-back pain, sciatica, claudication, or previous problems involving the lower limbs. These individuals, who had a mean age of forty-two years, were then subdivided into those who did not have a herniated disc on the magnetic resonance scans (Group I; forty-six patients) and those who did (Group II; twenty-one patients). The symptomatic patients who had a herniated disc confirmed operatively made up Group III, and the symptomatic patients who had degenerative spondylolisthesis at the level of the fourth and fifth lumbar vertebrae made up Group IV. The scans of the asymptomatic individuals had been previously interpreted by three blinded observers and had been used in a study that documented abnormal findings on the magnetic resonance scans of nineteen (28 per cent) of sixty-seven asymptomatic individuals⁴. A herniated disc was considered to be an extrusion (mainly focal) of disc material beyond the osseous confines of the vertebral body, resulting in the displacement of epidural fat, nerve root, or thecal sac. A bulge was defined as a diffuse (usually non-focal) protrusion of non-osseous material beyond the normal disc space.

Measurement of the Facet Angle

For each interspace between the second lumbar and first sacral vertebrae, an axial magnetic resonance scan was made aligned parallel to the end plate at the level of the inferior margin of the intervertebral disc space.

Scans were not used if the angle of the axial slice deviated by more than 5 degrees from the end plate. The images were scanned with a video camera (Sony, Tokyo, Japan), magnified, and stored in digitized form with use of image-capture software on a microcomputer (IBM PS2/90). The operator defined the coronal reference plane by marking two points on the posterior wall of the vertebral body or intervertebral disc (Fig. 1-A). When these landmarks were unclear, two points in the midline at the base and tip of the spinous process were identified, the sagittal plane was defined, and the computer calculated a perpendicular line to define the coronal plane. Two additional points were used to define the anteromedial and posterolateral margins of each facet joint (Fig. 1-B). The facet joint angle relative to the coronal plane and the difference between the angle for the right facet and the angle for the left facet at each level (tropism) were then calculated. All facet angles were measured independently by two observers who were blinded with regard to the diagnosis, and a mean value was calculated for each facet angle. After all measurements had been calculated, the data were grouped according to the predetermined criteria.

Validation of the Measurement Technique

To validate the measurement technique on magnetic resonance scans, measurements were also made independently on computed tomography scans that were available for five of the patients who had degenerative spondylolisthesis. The anatomical landmarks of the facets were not as clearly visualized on the magnetic resonance images of these patients, and they represented a worst-case scenario. Computed tomography and magnetic resonance scans of the same thirty facet joints were measured independently by the same two observers, and the Pearson correlation coefficient was calculated. To estimate intraobserver error, the mea-

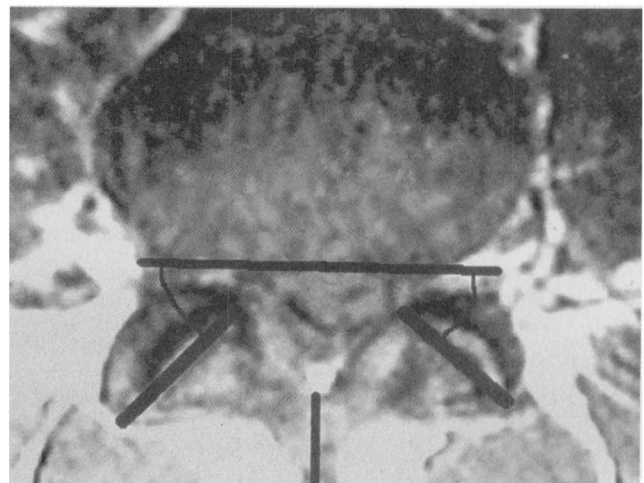


FIG. 1-A

Magnetic resonance image of the lumbar spine, demonstrating how the facet joint angles were measured relative to the coronal plane (horizontal line).

surements on the thirty facets were repeated by both of the observers several hours later. The primary source of error was in the identification of the reference plane and the margins of the facet joint, which is operator-dependent. To examine interobserver error, all of the 950 measurements made in duplicate by each observer were compared with use of Pearson correlation. In addition, the intraobserver and interobserver errors in degrees were calculated as $\sqrt{\Sigma(x_1 - x_2)^2/2n}$, where x_1 is the first measurement, x_2 is the second measurement, and n is the total pairs of observations.

Classification of Disc Degeneration

Disc degeneration was classified from the T1 and T2-weighted sagittal magnetic resonance scans with use of a system that has been shown to correlate with the provocation of pain on discograms, as described by Horton and Daftari. We used this schema to assign a point value to the different grades of annular and nuclear degeneration. The annulus was graded as flat (0 points), bulging (1 point), or torn (2 points), and the nucleus was graded as white (0 points), speckled (1 point), or dark (2 points). Each scan was scored independently by two observers, and the mean scores were calculated. The mean scores for the annulus and nucleus were then added together to provide a score for over-all disc degeneration. The total possible disc-degeneration score, therefore, ranged from 0 to 4 points.

Data and Statistical Analysis

The median facet tropism was determined at each lumbar level for Groups I, II, and III. In addition, tro-

TABLE II
FINDINGS ON MAGNETIC RESONANCE SCANS
OF ASYMPTOMATIC INDIVIDUALS*

	Nucleus			Total
	Dark	Speckled	White	
Annulus				
Torn	8 (3)	15 (6)	0 (0)	23 (9)
Bulging	19 (7)	29 (11)	10 (4)	58 (22)
Flat	15 (6)	106 (40)	66 (25)	187 (70)
Total	42 (16)	150 (56)	76 (28)	268

*The values given are the numbers of asymptomatic lumbar discs (from the second lumbar to the first sacral vertebra) that had the finding on the T2-weighted image. The percentages are given in parentheses.

pism was determined in Group III at only the interspaces at which a herniated disc had been confirmed operatively. Differences in the median values were tested with the Mann-Whitney U rank-sum test. Facet tropism was mathematically defined in the asymptomatic volunteers with use of a cumulative frequency distribution: none (the fiftieth percentile or less), mild (more than the fiftieth to the seventy-fifth percentile), moderate (more than the seventy-fifth to the ninety-fifth percentile), and severe (more than the ninety-fifth percentile). The relationship of facet tropism to the total disc-degeneration score as well as to just the score for the nucleus pulposus was tested at each lumbar level with analysis of variance. The relationship between facet tropism and disc herniation was tested at each level with the chi-square test for trend, and an odds ratio with Yates correction was calculated when p was less than 0.05. The relationship between the facet joint angle and

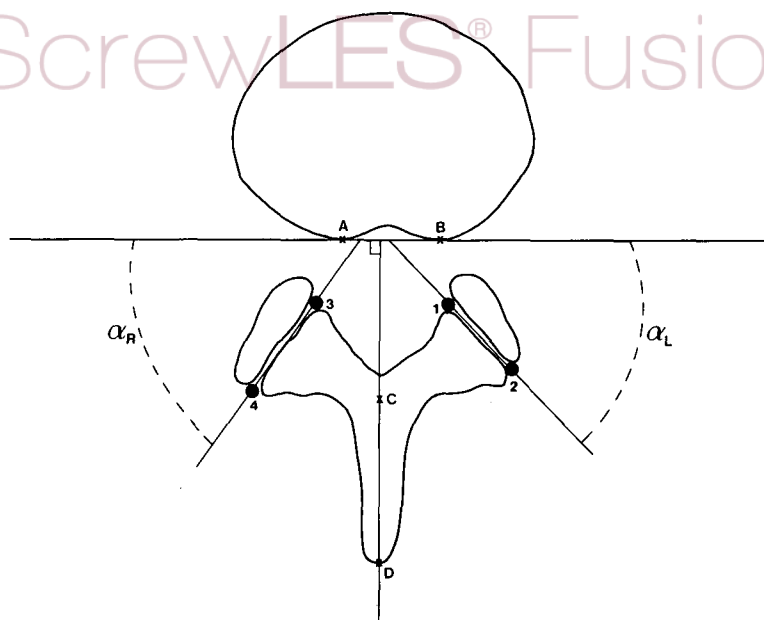


FIG. 1-B

Illustration of the reference plane that was defined by the posterior aspect of the disc space (A and B) or by a line drawn perpendicular to the spinous process (C and D). Two points were then used to define the margins of the left (1 and 2) and the right (3 and 4) facet joint, and the angles α_L and α_R were calculated automatically by the computer.

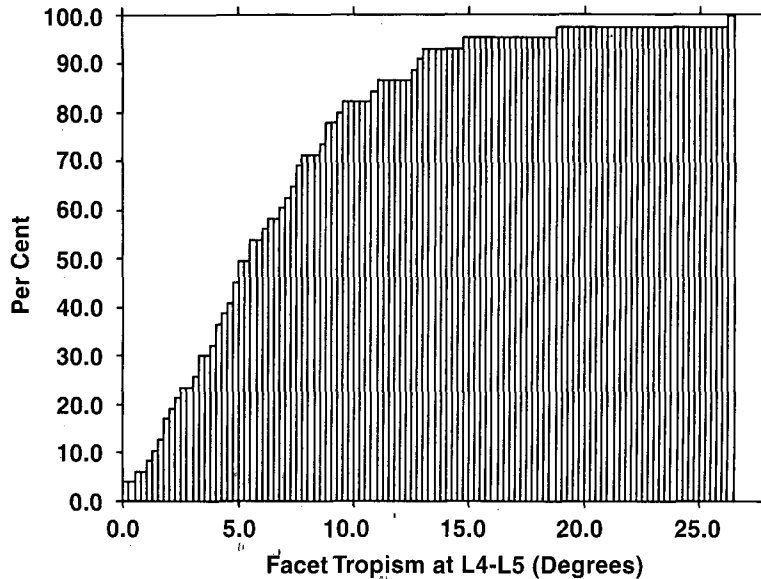


FIG. 2

Cumulative frequency distribution of facet tropism at the level of the fourth and fifth lumbar vertebrae, as measured on the magnetic resonance scans of the forty-six asymptomatic individuals who did not have a herniated disc evident on the scan (Group I). The y axis represents the percentage of subjects who had facet tropism at or below the value on the x axis.

disc herniation was tested at each level with the Fisher exact test. The mean, standard error of the mean, and 95 per cent confidence intervals were calculated for the orientation of the facet joint at each lumbar level for the asymptomatic volunteers (Groups I and II) and the patients who had degenerative spondylolisthesis (Group IV). Differences between means were tested at each level with the unpaired two-tailed Student t test and at all levels with analysis of variance. The relationship between sagittal orientation of the facet and degenerative spondylolisthesis was determined with the Fisher

exact test, and an odds ratio was calculated. All statistical tests were performed with Epistat 4.2 software (Epistat, Richardson, Texas).

Results

Validation and Reproducibility of the Measurement Technique

The correlation coefficient for the facet angles measured independently on both the magnetic resonance scans and the computed tomography scans was $r = 0.92$ ($p = 0.00001$). The correlation coefficient for both in-

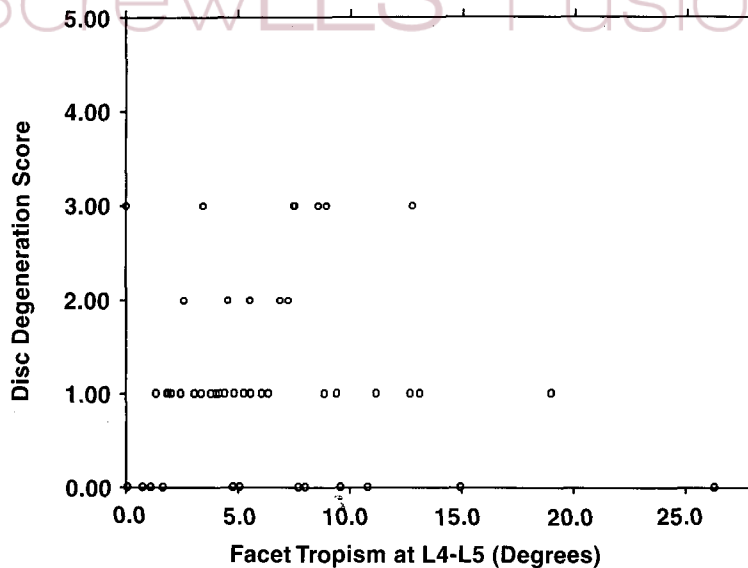


FIG. 3-A

Figs. 3-A, 3-B, and 3-C: Scattergrams of the disc degeneration score and facet tropism at the level of the fourth and fifth lumbar vertebrae. Fig. 3-A: The forty-six asymptomatic individuals who did not have disc herniation evident on the magnetic resonance scan (Group I). There is no association between disc degeneration and facet tropism.

traobserver and interobserver variation was $r = 0.99$ ($p = 0.00001$). The interobserver error was estimated to be ± 1.2 degrees and the intraobserver error, ± 1.7 degrees. These data validate the capacity of the method used to measure facet angles on magnetic resonance scans, and they establish the over-all error of measurement (2.9 degrees) as comparable with that seen with computed tomography¹⁰.

Disc Degeneration in Asymptomatic Individuals

Twenty-one (31 per cent) of the sixty-seven asymptomatic individuals (Groups I and II) were seen to have a herniated disc on the magnetic resonance scans, as

indicated by a bulging or torn annulus. Thirty-six (54 per cent) had evidence of a herniated disc or disc degeneration. A decrease in the signal intensity of the intervertebral disc on magnetic resonance scans is thought to represent degeneration. A dark and torn pattern has been previously shown to correlate with clinical symptoms of back pain¹². A speckled intranuclear signal pattern may be seen in symptomatic individuals, but it has also been seen in those who are asymptomatic. No subject had a white and torn pattern. Over-all, only seventy-six (28 per cent) of the 268 disc levels in the asymptomatic subjects had a white nuclear signal, 150 (56 per cent) were speckled, and forty-two (16 per

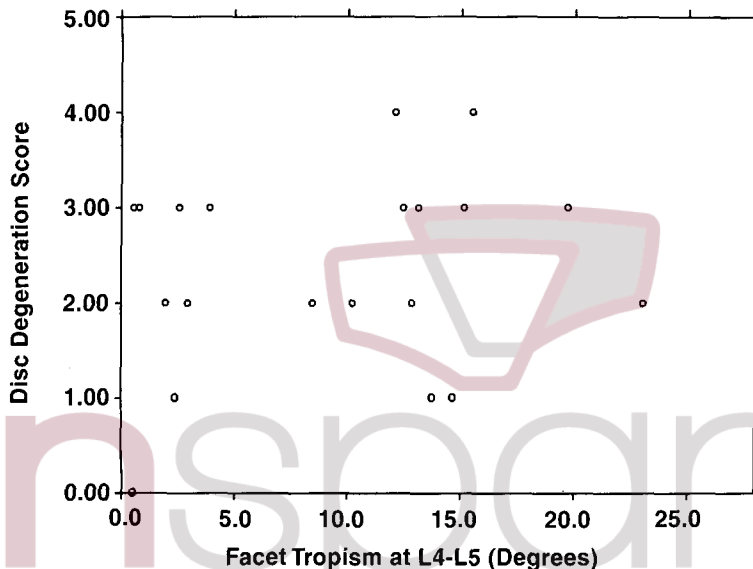


FIG. 3-B

The twenty-one asymptomatic individuals who had disc herniation (Group II). There is no association between disc degeneration and facet tropism.

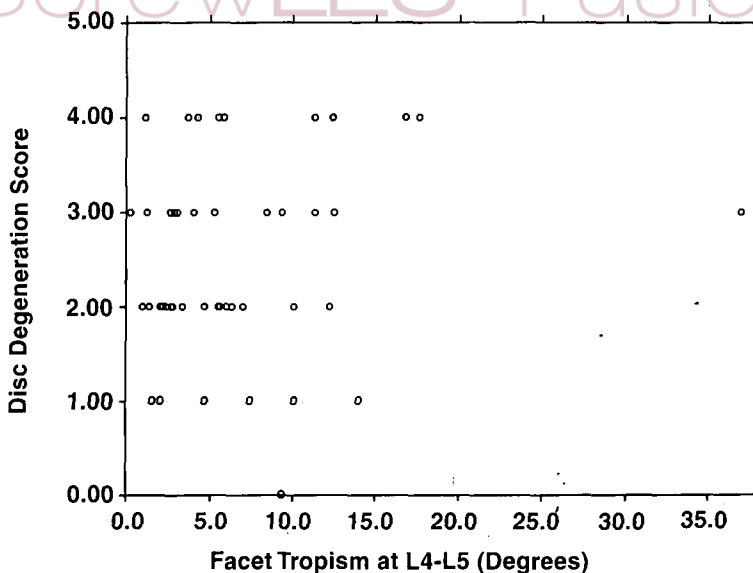


FIG. 3-C

The forty-six symptomatic patients who had disc herniation (Group III). There is no association between disc degeneration and facet tropism.

TABLE III
DISC DEGENERATION SCORES*

	Score (Points)				
	0	1	2	3	4
Group I (n = 46)					
L5-S1	13 (28)	24 (52)	6 (13)	3 (7)	0
L4-L5	12 (26)	22 (48)	6 (13)	6 (13)	0
L3-L4	13 (28)	23 (50)	6 (13)	4 (9)	0
Group II (n = 21)					
L5-S1	2 (10)	4 (19)	2 (10)	7 (33)	6 (29)
L4-L5	1 (5)	3 (14)	6 (29)	9 (43)	2 (10)
L3-L4	3 (14)	6 (29)	10 (48)	2 (10)	0
Group III (n = 46)					
L5-S1	1 (2)	8 (17)	1 (2)	18 (39)	18 (39)
L4-L5	1 (2)	6 (13)	17 (37)	12 (26)	10 (22)
L3-L4	5 (11)	15 (33)	15 (33)	9 (20)	2 (4)

*The values given are the numbers of subjects, with the percentages in parentheses. The score, as calculated from the T2-weighted magnetic resonance scan, was the sum of the score for the annulus (0 = flat, 1 = bulging, and 2 = torn) and the score for the nucleus (0 = white, 1 = speckled, and 2 = dark).

cent) were dark (Table II). Group I had a lower disc-degeneration score than both Group II and Group III (Table III). There was no substantial difference in the pattern of disc degeneration between Group II and Group III.

Facet Tropism in Asymptomatic Individuals

To define the distribution of facet tropism in the asymptomatic individuals, only the facet measurements from Group I were included (Fig. 2). With use of the cumulative frequency criteria outlined earlier, the asymptomatic individuals were considered to have no facet tropism if the mean asymmetry was 6 degrees or less, mild tropism if it was more than 6 to 10 degrees, moderate tropism if it was more than 10 to 16 degrees, and severe tropism if it was more than 16 degrees (Table IV). The median facet tropism was 5 to 6 degrees in Group I and represented the value at which half of the subjects had a greater degree and half, a lesser degree of tropism.

Facet Tropism and Disc Degeneration

There was no association between either the presence or the severity of facet tropism and disc degeneration in any of the patients who had disc degeneration. This analysis was performed for each lumbar level independently (Figs. 3-A, 3-B, and 3-C) and it was also performed for all levels combined with use of the over-all disc-degeneration score. There was also no association between facet tropism and decreased signal intensity in the nucleus pulposus on the T2-weighted magnetic resonance scans.

Facet Tropism and Disc Herniation

The patients in Group III who had a herniated disc at the level of the fourth and fifth lumbar vertebrae had a significantly higher median facet tropism (10.3

degrees) at that level than the individuals in Group I (5.4 degrees) ($p = 0.05$). This association was not found at the level of the fifth lumbar and first sacral or the third and fourth lumbar vertebrae (Table V). In addition, this relationship was not discernible when all four lumbar levels from Group III were grouped; it was found only when tropism was measured at just the levels with herniation (Table V). To investigate this observation further, the prevalence and severity of facet tropism was examined in the asymptomatic individuals (Groups I and II) and in the symptomatic patients who had a herniated disc (Group III). A relationship between disc herniation and increased severity of facet tropism ($p = 0.03$) was seen only in the symptomatic patients who had a herniated disc at the level of the fourth and fifth lumbar vertebrae (Table VI). The patients who had severe facet tropism at this level had a 6.6 times greater risk of disc herniation (95 per cent confidence interval, 0.8 to 77.4 times).

Facet Orientation and Disc Herniation

The relationship between sagittal orientation of the facet joint and disc herniation in Group III was compared with that in Group I. When both the left and the right facet joints at the level of the fourth and fifth lumbar vertebrae were sagittally oriented (more than 45 degrees), there was a significant association with symptomatic disc herniation at that level ($p = 0.04$). The odds ratio suggests that an individual in whom both facet angles are more than 45 degrees has a 2.9 times greater risk of disc herniation at that level (95 per cent confidence interval, 0.9 to 9.7 times). A trend toward a similar relationship was seen at the level of the fifth lumbar and first sacral vertebrae ($p = 0.09$).

Facet Orientation and Degenerative Spondylolisthesis

The mean facet angles (measured relative to the coronal plane) at the levels of the third and fourth lumbar vertebrae, the fourth and fifth lumbar vertebrae, and the fifth lumbar and first sacral vertebrae were significantly greater ($p = 0.00001$) in the patients who had degenerative spondylolisthesis (Group IV) than in the asymptomatic individuals (Groups I and II) (Table VII). The greatest difference was at the level of the slip (the fourth and fifth lumbar vertebrae): the asymptomatic

TABLE IV
DEFINITION OF FACET TROPISM (Degrees) IN GROUP I
BY CUMULATIVE FREQUENCY DISTRIBUTION

Level	None (≤50th Percentile)	Mild (>50th to 75th Percentile)	Moderate (>75th to 95th Percentile)	Severe (>95th Percentile)
L5-S1	6	11	18	>18
L4-L5	5	8	15	>15
L3-L4	7	11	15	>15
L2-L3	6	10	16	>16
Mean*	≤6	≤10	≤16	>16

*The mean tropism for the four lumbar levels.

TABLE V
MEDIAN FACET TROPISM (Degrees)

Level	Group I	Group II*	Group III	
			Over-All*	With Herniated Disc at That Level
L5-S1	5.9	6.6	5.6	5.5
L4-L5	5.4	11.1†	5.4	10.3†
L3-L4	6.9	3.6	4.9	2.0
L2-L3	5.0	7.9	4.9	—

*The median facet tropism was determined at each level in all subjects regardless of whether or not there was a herniated disc at that level.

†P = 0.05 compared with Group I (Mann-Whitney U rank-sum test).

individuals had a mean angle of 41 degrees (95 per cent confidence interval, 37.6 to 44.6 degrees), and the patients who had degenerative spondylolisthesis had a mean angle of 60 degrees (95 per cent confidence interval, 52.7 to 67.1 degrees). With regard to the facet orientation at the level of the fourth and fifth lumbar vertebrae, the mean difference between the groups was 19 degrees ($p = 0.000001$). Furthermore, sagittal orientation (more than 45 degrees) of both the left and the right facet showed a strong relationship with degenerative spondylolisthesis; such an orientation was seen in ten of sixty-six asymptomatic patients, compared with twenty-two of twenty-seven patients who had degenerative spondylolisthesis ($p = 0.000001$). Calculation of the odds ratio suggested that an individual in whom both facet-joint angles at the level of the fourth and fifth

TABLE VI
SEVERITY OF FACET TROPISM*

Level	None	Mild	Moderate	Severe
L5-S1				
Group I (n = 43)	22	11	7	3
Group II (n = 20)	10	7	1	2
Group III (n = 45)				
Over-all	23	12	8	2
With herniated disc at L5-S1 level	23	11	4	3
L4-L5				
Group I (n = 46)	21	12	11	2
Group II† (n = 20)	8	0	8	4
Group III (n = 46)				
Over-all	22	9	12	3
With herniated disc at L4-L5 level‡	8	2	9	5
L3-L4				
Group I (n = 45)	23	11	8	3
Group II (n = 21)	18	0	1	2
Group III (n = 45)				
Over-all	28	8	5	4
With herniated disc at L3-L4 level	7	1	0	0

*The values given are the numbers of subjects, which do not always equal the number available because the axial scan did not allow determination of the facet angle for every subject.

†Significant ($p < 0.05$) compared with Group I (chi-square test for trend).

‡Significant ($p = 0.03$) compared with Group I.

lumbar vertebrae were greater than 45 degrees was twenty-five times more likely to have degenerative spondylolisthesis (95 per cent confidence interval, seven to ninety-eight times).

Discussion

A relationship between asymmetry of the lumbar facets and disc abnormality was suggested by Farfan et al. and by others^{3,11,13}. In 1980, Cyron and Hutton postulated that tropism could lead to instability, with the joints rotating toward the side of the most oblique facet. Van Schaik et al. used computed tomography to measure tropism in 100 patients who had low-back pain or sciatica, or both, and found a relationship between facet tropism and disc herniation at the level of the fourth and fifth lumbar vertebrae^{19,20}. Noren et al. studied fifty-four patients who had back pain and reported an association between disc degeneration (including herniation) and facet tropism at all lumbar levels. They used magnetic resonance scans to determine disc degeneration and computed tomography to measure facet tropism.

In contrast, other studies have suggested that facet tropism has no clinical relevance. In 1981, Adams and Hutton performed a biomechanical analysis and concluded that axial torsion was not important in the development of disc degeneration. Hagg and Wallner did not find any association between tropism and herniated discs in forty-seven patients who had herniated discs, although they noticed increased asymmetry at the level of the fourth and fifth lumbar vertebrae in these patients. Cassidy et al. studied 136 patients who had herniated discs and did not find a clinically relevant association with facet tropism; however, they did find a small increase in asymmetry at the level of the fifth lumbar and first sacral vertebrae in thirty patients. In the latter two studies, adjacent levels without herniation in the same patients were used as controls. Vanharanta et al. studied the computed tomography scans and discograms of 108 patients who had low-back pain and concluded that there was no association between facet tropism and disc degeneration or provocation of pain. That study also clearly documented that there was no difference in facet angles between male and female subjects.

Several authors^{1,2,6,10,18} have suggested that a central flaw that continues to drive this controversy is the lack of normative data on facet tropism. A primary goal of the present study was to acquire such data from magnetic resonance scans of asymptomatic volunteers.

Most individuals have some degree of facet asymmetry, but the definition of excessive asymmetry or tropism is somewhat arbitrary. We chose to define it mathematically with use of a cumulative frequency distribution obtained from asymptomatic individuals who did not have a herniated disc on magnetic resonance scans. Independent of the definition of normal tropism, our study demonstrated that the absolute magnitude of

TABLE VII
RELATIONSHIP BETWEEN FACET ORIENTATION AND DEGENERATIVE SPONDYLOLISTHESIS

Level	Side	Asymptomatic Individuals			Patients Who Had Degenerative Spondylolisthesis			P Value
		No.	Facet Angle (Degrees)*		No.	Facet Angle (Degrees)*		
			Mean and Standard Error of Mean	95 Per Cent Confidence Interval		Mean and Standard Error of Mean	95 Per Cent Confidence Interval	
L5-S1	R	63	39 ± 1.3	36.4-41.4	25	44 ± 2.9	38.2-50.2	0.05
	L	63	37 ± 1.2	34.5-39.2	25	43 ± 2.7	37.8-48.9	0.01
L4-L5	R	66	42 ± 1.3	39.3-44.6	27	59 ± 3.1	52.7-65.6	0.000001
	L	66	40 ± 1.4	37.6-43.2	27	62 ± 2.5	56.7-67.1	0.000001
L3-L4	R	66	51 ± 1.1	48.6-53.2	27	61 ± 2.3	56.3-65.9	0.00004
	L	66	49 ± 1.3	46.6-51.7	27	60 ± 2.3	54.8-64.2	0.00006
L2-L3	R	16	59 ± 3.5	51.7-66.5				
	L	16	56 ± 3.2	49.2-62.7				

*Facet orientation was defined as the angle formed at the intersection of the joint line with the coronal plane, as measured on the axial magnetic resonance scans. The number of subjects does not always equal the number available because the axial scan did not allow determination of the facet angle for every subject.

facet tropism at the level of the fourth and fifth lumbar vertebrae in patients who had herniated discs was double that of asymptomatic individuals. The lack of correlation of facet tropism with herniation of the disc at the level of the fifth lumbar and first sacral vertebrae may reflect the decreased importance of joint asymmetry at a segment that is more firmly stabilized by the iliolumbar ligaments.

Despite several studies that have suggested a relationship, we were unable to document any association between facet tropism and degeneration of the annulus fibrosus or nucleus pulposus on magnetic resonance scans. Two previous studies^{15,20} that showed such a relationship both used computed tomography scans of patients who had low-back pain rather than those of normal controls. While the scoring system that we used may not be universally accepted, we chose it because it permitted the most detailed recording of changes in both the annulus fibrosus and the nucleus pulposus independently and gave us the greatest opportunity to see subtle correlations. We were able to document and classify the high prevalence of changes in the nucleus pulposus and annulus fibrosus seen on magnetic resonance scans in asymptomatic subjects (Table II). Such information is of paramount importance when interpreting the clinical relevance of these findings on scans of symptomatic individuals.

The absolute orientation of the facet joints has been less well studied than tropism¹⁷. In the present investigation, we found that more sagittally oriented facet joints at the level of the fourth and fifth lumbar vertebrae were highly associated with herniated discs and degenerative spondylolisthesis. Until recently, the precise etiology of degenerative spondylolisthesis had been uncertain^{14,16}. Grobler et al. compared the facet measurements made on computed tomography scans of twenty-six patients who had spondylolisthesis with those on the

scans of twenty-five patients who had low-back pain (controls). They found a more sagittal orientation of the facet joints at the level of the fourth and fifth lumbar vertebrae in the patients who had degenerative spondylolisthesis⁹. We had similar findings in our study; however, we used true (asymptomatic) controls and demonstrated a more sagittal orientation of the facets not only at the level of the slip but also at levels (the third and fourth lumbar vertebrae and the fifth lumbar and first sacral vertebrae) that had no evidence of degenerative spondylolisthesis. This latter observation strongly suggests that the increased facet angle at the level of the slip was not simply due to remodeling of the facet after slippage but rather was part of a predisposing morphological joint configuration seen at multiple lumbar levels in certain patients. More simply, the sagittal orientation of the facets was part of the pre-existing morphology and was not solely a secondary result of spondylolisthesis. We extended the observations of Grobler et al. by calculating the high-risk facet-orientation threshold of 45 degrees and the associated odds ratio. This critical threshold is also substantiated by demonstration that the 95 per cent confidence intervals for the mean facet angle did not overlap between the asymptomatic patients and those who had degenerative spondylolisthesis (Table VII).

The strengths of the present investigation include the use of a large sample of asymptomatic controls as well as two independent and blinded measurements of each facet angle. The measurement technique was highly reproducible, and the actual measurements were consistent with values available from several previous studies in which computed tomography scans were used^{15,20}. Our methodology provided normative data as well as evidence of the clinical relevance for additional study of the orientation of the lumbar facet joint and facet tropism.

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