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Predictive Value and Inter-Rater Reliability of Radiographic Factors in Neurofibromatosis Patients with Dystrophic Scoliosis

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Abstract

Background—Scoliosis in patients with neurofibromatosis type I (NF1) can manifest as dystrophic or nondystrophic curves. Dystrophic scoliosis is rapidly progressive, rendering treatment challenging. Radiographic characteristics have been reported to predict dystrophic scoliosis, but their reliability and predictive value have not been well described. The purpose of this study is to assess the inter-observer reliability for eight radiographic characteristics of dystrophic scoliosis and to evaluate the sensitivity and specificity of these characteristics relative to the ‘gold standard’ of a definitive clinical diagnosis.

Methods—Spine radiographs of 122 NF1 patients from multiple institutions were graded by five spine surgeons as dystrophic or nondystrophic, based on eight radiographic characteristics of dystrophic modulation: rib penciling, vertebral rotation, scalloping, wedging, spindling of transverse processes, short sharp angular curve, widened interpedicular distance, and atypical location. The curves were classified by each submitting institution as dystrophic or nondystrophic based on clinical outcome. Inter-observer reliability analysis was performed using Fleiss’ kappa.

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Results—For the 122 cases, the inter-rater agreement among the five readers for the diagnosis of dystrophic scoliosis was good at 0.61. The agreement for individual radiographic characteristic ranged from 0.62 for wedging to 0.14 (poor) for scalloping. Surgeons underestimated the number of dystrophic curves, rating from 45–67% of the curve patterns as dystrophic, compared to the gold standard, which revealed 68% of the curves to be dystrophic. On multivariate analysis, rib penciling, vertebral rotation, vertebral wedging, and atypical location were significantly associated with true dystrophic status (odds ratios of 2.4, 3.0, 2.4, and 3.0, respectively).

Conclusion—Overall dystrophic diagnosis can be assessed by radiographic characteristics. Better understanding of the predictive value of specific radiographic features may assist in early diagnosis of patients with dystrophic NF and assist surgeons in identifying dystrophic curve patterns and instituting prompt, appropriate treatment.

Level of Evidence—3

Keywords

nondystrophic; modulation; neurofibroma; rib penciling

INTRODUCTION

Neurofibromatosis type 1 (NF1) is an autosomal dominant genetic disorder occurring in approximately 1:4000 individuals worldwide across all ethnicities (1). The NF1 gene mutation leads to loss of the neurofibromin protein which downregulates p21-Ras, an oncogene. For unknown reasons, scoliosis, kyphosis, and spinal deformity are among the most common skeletal problems in patients with NF1 with a prevalence of 8–60% (2, 3). A distinctive osseous lesion such as dystrophic scoliosis is included in the clinical criteria for diagnosis of NF1 (4). There are two types of scoliosis associated with NF1 - nondystrophic and dystrophic curve patterns (5). Nondystrophic scoliosis behaves and evolves similarly to that of idiopathic scoliosis patients and may be amenable to bracing and observation. Dystrophic changes do not always appear at initial presentation and may progress over time. Dystrophic scoliosis is associated with rapid progression and poor prognosis and has specific radiographic findings (Table 1) (5). Therefore, the development and validation of a radiographic scheme to distinguish dystrophic and nondystrophic disease would be beneficial, allowing for early detection and appropriate treatment interventions. Careful validation of these predictive factors may facilitate early detection and timely treatment interventions to improve outcomes, as dystrophic curve patterns frequently require surgical management (6).

Predictive rating systems must have high inter-rater reliability to be generalizable. There is limited data regarding the inter-rater reliability of the specific radiographic features of a dystrophic curve pattern. We hypothesized that the early radiographic findings of NF1 dystrophic scoliosis as described by Durrani et al. would have a high inter-rater reliability and be predictive of future progressive dystrophic disease (5). We further sought to determine which specific radiographic factors seen on presenting radiographs are most predictive of a dystrophic curve.

METHODS

A digitized multicenter database of 122 presenting radiographs for established patients with scoliosis, NF1, and known clinical outcome (dystrophic vs. nondystrophic curve pattern) was assembled. Sites submitted PA and lateral radiographs taken at presentation to orthopedics for the database. Cases included patients with operative and nonoperative management, and sites were asked to submit cases across the spectrum of their practice with a variety of disease severity. Sites also submitted the 'gold standard' diagnosis, as these patients had been followed over time at the individual sites until either surgical intervention or skeletal maturity. The sites thus provided the 'gold standard' diagnosis for each case based on behavior of the curve over time. Further data such as age at presentation, genetic confirmation of diagnosis, indications for surgical treatment, or outcomes were not collected. Five experts who specialize in NF1 spinal deformities evaluated a series of spinal radiographs to assess inter-rater reliability and the predictive value for radiographic characteristics of dystrophic disease. A refined checklist of radiographic findings suggestive of dystrophic curves was developed (Table 2). For simplicity, the Durrani et al. criteria of anterior, lateral, posterior vertebral scalloping, and enlarged intervertebral foramina were condensed into a single category of vertebral body scalloping (5). Additionally, two new criteria were added: atypical curve location and short sharp angular curve. Standardized definitions for each of the 8 characteristic findings were developed (Figure 1). Both dystrophic and nondystrophic curve patterns were included. Five orthopedic spine surgeons reviewed the assembled cases (ANL, DWP, LYC, AHC, DJS). Experts were blinded as to whether each case example represented a dystrophic or a nondystrophic deformity. Each expert was then asked whether each radiographic feature was present or absent for every case example. Finally, experts were asked whether or not the curve pattern was dystrophic based on the radiographic data alone. Follow-up radiographs on all cases were available at each center and were reviewed by study authors to determine whether or not the curve proved to be dystrophic.. There was an Institutional Review Board determination that specific approval was not required for this study, as all radiographs were de-identified and formed a limited dataset.

Expert Observer Accuracy

The ability of the five surgeon readers to predict dystrophic diagnosis was assessed both using Cohen's kappa statistic to quantify the agreement between the readers' diagnoses and the true diagnoses, and using sensitivity and specificity to quantify the accuracy of the readers' diagnoses. Differences among readers' observations were assessed using Pearson's chi-square test.

Expert Observer Reliability

Inter-observer reliability was calculated using Fleiss' kappa measure of agreement, using the MAGREE macro in SAS 9.2 (SAS Institute, Cary, NC) and was double-checked using the kappam.fleiss function in R (7). All kappa values were interpreted according to Byrt et al., with agreements assessed as 0.93–1.00 excellent, 0.81–0.92 very good, 0.61–0.80 good, 0.41–0.60 fair, 0.21–0.40 slight, and 0.01–0.20 poor (8).

The sample size necessary for the inter-observer reliability assessment was estimated using the following power analysis. Assuming that the proportion of agreement between two experts would be 70%, and seeking to estimate the true level of agreement within a 95% confidence level margin of error of 10%, a sample size of 81 patient radiographs would be required.

Predictive Value of Dystrophic Radiographic Features: Sensitivity and Specificity

Sensitivity and specificity for dystrophic scoliosis were assessed for each of the eight radiographic characteristics individually using the established clinical diagnosis as the gold standard. The association between presence of a characteristic and either predicted or true dystrophic diagnosis was assessed using Pearson's chi-square test. In addition, a multiple logistic regression analysis was undertaken to assess which combination of the eight characteristics most accurately and precisely predicts dystrophic scoliosis, with the known dystrophic status as the binary outcome and the eight radiographic characteristics used as binary predictors. Backward selection was used to eliminate non-significant characteristics from the model. The sensitivity and specificity of the resulting logistic regression predictive model were assessed using the established clinical diagnosis as the gold standard.

All statistical analyses were carried out using SAS Version 9.2 or R Version 2.14.

RESULTS

Spinal radiographs from 122 NF1 patients were evaluated independently by five orthopedic surgeons for presence or absence of the eight dystrophic features, for a total of 610 case reviews. Surgeons also rated whether each curve pattern was dystrophic vs. nondystrophic. The gold standard of dystrophic or nondystrophic curve pattern was determined by the contributing institution based on longitudinal follow-up.

Accuracy of Radiographic Prediction of a Dystrophic Curve Pattern

Each surgeon's predicted diagnosis of dystrophic vs. nondystrophic scoliosis was compared to the actual diagnosis. Overall, 363 of the 610 case reviews (60%) deemed the curve pattern to be dystrophic. For a given reader, the proportion deemed dystrophic ranged from 45% to 67% (Table 3).

The differences among readers were statistically significant (Pearson's chi-square test, p -value = 0.0060). All of the readers underestimated the number of curves that were dystrophic. The agreement between the true diagnosis and the overall readers' diagnoses, as assessed using Cohen's kappa statistic, was 0.44 or 'fair'. For the 415 truly dystrophic x-rays, the expert readers overall were correct 75% of the time. Similarly, for the 195 readings on x-rays that were truly nondystrophic, the expert readers had a specificity of 73% (142/195 reads). With a sample size of 122 x-rays, the margin of error for both the sensitivity and specificity is about 8. Overall sensitivity among the reviewers ranged from 62% to 77%, and specificity ranged from 67–69%. Overall level of agreement with actual diagnosis (Cohen's kappa) only achieved fair agreement at 0.44 (range, 0.41–0.49).

Of the 83 truly dystrophic x-rays, all five readers correctly classified 42 (50.6%) as dystrophic. Eight radiographs (9.6%) were incorrectly classified as nondystrophic by all five readers. There was disagreement for the remaining 33 (39.8%) dystrophic x-rays. Similarly, of the 39 nondystrophic x-rays, 22 (56.4%) were classified correctly by all five readers, four (10.3%) were classified incorrectly by all five readers, and there was disagreement about the remaining 13 (33.3%).

Reproducibility of Dystrophic Diagnosis and Radiographic Features: Agreement among Observers

For dystrophic diagnosis, there was good agreement among the observers when they reviewed the x-rays from initial presentation (Fleiss' kappa 0.61) (Table 4). The five surgeons agreed that a case was dystrophic in 46 of 122 cases, and nondystrophic in 30 of 122 cases. Parameters which had the greatest inter-rater reliability included vertebral wedging and short sharp angular curve, while there was poor inter-rater reliability for atypical location, widened interpedicular distance, and vertebral scalloping.

Predictive Value of Dystrophic Radiographic Features: Observers' Ratings vs. Actual

When an observer noted the presence of a dystrophic feature on the radiograph, this was associated with an increased chance of rating the curve dystrophic for all 8 features (chi-square, $p < 0.0001$). Thus, observers assigned a value for each radiographic feature to predict the presence of a dystrophic curve (Table 5). Observers were most likely to state that curves with wedging, rotation, and short sharp angular curve were dystrophic.

These associations persisted when the true diagnosis of a dystrophic curve was utilized (Table 6). All eight observed characteristics were significantly associated with a true dystrophic curve pattern. Three radiographic criteria were most sensitive for true dystrophic curve patterns – vertebral wedging, rotation, and a short sharp angular curve. The absence of an atypical curve location, spindling of the transverse processes, widened interpedicular distance or rib penciling were most characteristic of a nondystrophic curve pattern. With the exception of rib penciling, these features were present in fewer than half of the true dystrophic cases.

Radiographic Factors Most Predictive of a Dystrophic Curve

Multiple logistic regression using backward selection was carried out in order to determine which combination of radiographic characteristics was most predictive of true dystrophic status. Four characteristics (spindling of transverse processes, short sharp angular curve, widened interpedicular distance and vertebral scalloping) were eliminated from the analysis since they were not significant ($p > 0.05$). Rib penciling, vertebral rotation, vertebral wedging, and atypical location were strongly associated with true dystrophic status (Table 7). When multiple radiographic characteristics are present, the predictive value is increased. The model predicts that the probability of a case being dystrophic is about 31% if the reader saw none of these four characteristics. The probability rises to 52–58% if the reader saw one of the four characteristics, 72–80% if two are present, 88–91% with three present, and 96% if all four were present (Figure 2). Thus, the presence of rib penciling, vertebral rotation,

vertebral wedging, and atypical location were highly predictive of a dystrophic curve pattern, and presence of any three of the four also was highly predictive (88–91%).

DISCUSSION

Dystrophic features in NF1 scoliosis patients are associated with rapid curve progression and need for future surgical management (6). Early detection of dystrophic curves facilitates appropriate monitoring and prompt treatment. Early surgical intervention may help avoid complex or higher risk spinal procedures required for large curve patterns such as anterior posterior spinal fusion, vertebral column resection and halo traction and may leave patients with less residual deformity (9, 10). Durrani et al. outlined predictive factors of a dystrophic curve pattern in patients with NF1 (5). We sought to evaluate the inter-rater reliability of these radiographic characteristics and to determine their value for prediction of dystrophic curve patterns in a large multicenter database of radiographic cases of scoliosis associated with neurofibromatosis. Durrani et al. found several factors predictive of a dystrophic curve pattern (5). These include age under 7 combined with vertebral wedging, posterior scalloping, spindled transverse processes, and/or rib penciling (Durrani et al., 2000). Funasaki et al. found vertebral scalloping, rotation, rib penciling, and a high Cobb angle to be predictive of progression (11, 12). In our series, we found that the most predictive factors for dystrophic curves were vertebral wedging and rotation. Rib penciling and atypical location were also highly predictive on multiple regression analysis.

Interestingly, inter-observer was good for vertebral wedging, fair for vertebral rotation and rib penciling, and poor for atypical location. This would suggest that wedging and rotation are two factors which are agreed upon by multiple readers and predictive of a dystrophic curve pattern. Further work to better define rib penciling and atypical location could potentially improve inter-observation variation. There are several limitations to our study. The study design was to evaluate for the presence or future development of dystrophic curve patterns based on presenting radiographs alone. For this purpose, we used a de-identified database of patient radiographs. We did not include patient predictive factors, such as age at presentation, curve progression over time, surgical outcomes, Cobb angle, or sagittal plane considerations, such as kyphosis, which are frequently seen in dystrophic curves. Rather we sought to focus on the classic characteristic radiographic factors associated with dystrophism in NF scoliosis. Certainly in practice, clinical judgment, curve magnitude, and age at presentation play a significant role in planning treatment. We utilized the treating center's ultimate diagnosis as the gold standard in determining which curves were dystrophic and which were nondystrophic. All patients had been followed over time at each site, in order to determine behavior of the curve. There may be institutional bias in case selection, as patients with more severe disease are more likely to be followed until skeletal maturity. However, sites were asked to contribute cases with a wide variety of disease severity, which should be in general representative of NF patients who are presenting spine deformity surgeons. The validation of predictive findings on an independent cohort of NF1 patients with known dystrophic status would potentially strengthen and refine our recommendations.

Dystrophism further may not be a binary phenomenon but rather a spectrum of disease severity. Further work with machine learning and computer algorithms may be better able to

address this concept. For the current work, we used the established literature definitions of dystrophic vs. nondystrophic curve patterns.

More recent studies have utilized axial imaging to further define features associated with dystrophic modulation (13). For instance, the presence of paraspinal neurofibromas seen on axial images were associated with progressive dystrophic scoliosis (13). However, these are not frequently detected on screening radiographs, which can be obtained at more frequent intervals for monitoring purposes. Other reports have added MR findings, such as paraspinal tumor or dural ectasia, to the list of dystrophic features and confirmed again that an increased number of dystrophic features were associated with the need for spinal surgery (6). Widened interpedicular distance and posterior scalloping have been associated with dural ectasia. While our data will assist surgeons in identifying the majority of dystrophic curves and in determining follow-up, axial imaging is strongly recommended prior to any surgical intervention in spinal deformity patients with NF1.

In summary, we evaluated the classic radiographic features of dystrophic scoliosis in NF1 for inter-rater reliability and predictive value for dystrophism. Inter-rater reliability was only fair for determining a dystrophic curve among an experienced group of surgeons, highlighting the need for better predictive algorithms for early identification of dystrophic curve patterns. The highest inter-rater reliability was found for vertebral wedging, short sharp angular curve, and rotation. These three features also had reasonable sensitivity and specificity for dystrophic curve patterns. Although atypical location, widened interpedicular distance, and transverse processes spindling were 80–93% specific for dystrophism, they were not sensitive. Multiple regression analysis revealed the simultaneous presence of vertebral wedging, vertebral rotation, atypical curve location and rib penciling to be 96% predictive for a dystrophic curve pattern, although it should be noted that vertebral wedging and rotation had the best interrater reliability. This information adds to the predictive factors as outlined by Durrani et al. and may assist surgeons who are following patients with NF spinal deformity to identify those at greatest risk for curve progression and dystrophism who require more frequent follow-up and earlier surgical intervention.

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References

1. McKeever K, Shepherd CW, Crawford H, Morrison PJ. An epidemiological, clinical and genetic survey of neurofibromatosis type 1 in children under sixteen years of age. *Ulster Med J*. 2008; 77(3):160–3. [PubMed: 18956796]
2. Akbarnia BA, Gabriel KR, Beckman E, Chalk D. Prevalence of scoliosis in neurofibromatosis. *Spine (Phila Pa 1976)*. 1992; 17(8 Suppl):S244–8. [PubMed: 1523507]
3. Calzavara PG, Carlino A, Anzola GP, Pasolini MP. Segmental neurofibromatosis. Case report and review of the literature. *Neurofibromatosis*. 1988; 1(5–6):318–22. [PubMed: 3152485]

4. Neurofibromatosis; National Institutes of Health Consensus Development Conference Statement: neurofibromatosis; Bethesda, Md., USA. July 13–15, 1987; 1988. 172–8.
5. Durrani AA, Crawford AH, Choudhry SN, Saifuddin A, Morley TR. Modulation of spinal deformities in patients with neurofibromatosis type 1. *Spine (Phila Pa 1976)*. 2000; 25(1):69–75. [PubMed: 10647163]
6. Lykissas MG, Schorry EK, Crawford AH, Gaines S, Rieley M, Jain VV. Does the presence of dystrophic features in patients with type 1 neurofibromatosis and spinal deformities increase the risk of surgery? *Spine (Phila Pa 1976)*. 2013; 38(18):1595–601. DOI: 10.1097/BRS.0b013e31829a7779 [PubMed: 23680833]
7. Team RC. R: A language and environment for statistical computing. Vienna, Austria: 2013. Available from: <http://www.R-project.org/>
8. Byrt T. How good is that agreement? *Epidemiology*. 1996; 7(5):561.
9. Koptan W, ElMiligui Y. Surgical correction of severe dystrophic neurofibromatosis scoliosis: an experience of 32 cases. *Eur Spine J*. 2010; 19(9):1569–75. DOI: 10.1007/s00586-010-1464-0 [PubMed: 20506026]
10. Wang Z, Fu C, Leng J, Qu Z, Xu F, Liu Y. Treatment of dystrophic scoliosis in neurofibromatosis Type 1 with one-stage posterior pedicle screw technique. *Spine J*. 2015; 15(4):587–95. DOI: 10.1016/j.spinee.2014.10.014 [PubMed: 25452011]
11. Funasaki H, Winter RB, Lonstein JB, Denis F. Pathophysiology of spinal deformities in neurofibromatosis. An analysis of seventy-one patients who had curves associated with dystrophic changes. *J Bone Joint Surg Am*. 1994; 76(5):692–700. [PubMed: 8175817]
12. Winter RB, Moe JH, Bradford DS, Lonstein JE, Pedras CV, Weber AH. Spine deformity in neurofibromatosis. A review of one hundred and two patients. *J Bone Joint Surg Am*. 1979; 61(5): 677–94. [PubMed: 110813]
13. Nguyen R, Dombi E, Akshintala S, Baldwin A, Widemann BC. Characterization of spinal findings in children and adults with neurofibromatosis type 1 enrolled in a natural history study using magnetic resonance imaging. *J Neurooncol*. 2015; 121(1):209–15. DOI: 10.1007/s11060-014-1629-5 [PubMed: 25293439]

Key Points

1. The highest probability of a dystrophic pattern is seen in scoliosis curves with rib penciling, vertebral rotation, vertebral wedging and an atypical curve location.
2. The best inter-rater reliability was seen for vertebral wedging, short sharp angular curve pattern, and vertebral rotation, while there was poor inter-rater reliability for vertebral scalloping, atypical curve location, and widened interpedicular distance.
3. Surgeons on the whole underestimated the number of curve patterns which were dystrophic.

Figure 1.

Radiographic features. A) Vertebral wedging with at least 5 degrees angulation between superior and inferior endplates. B) Vertebral rotation C) Short sharp angular curve D) Rib penciling with loss of at least 50% of the diameter of the rib, excluding T11 and T12, where ribs may be more gracile. E) Vertebral body scalloping. F) Widened interpedicular distance or absent pedicle. G) Atypical location in proximal thoracic or lumbar spine. H) Spindling of transverse processes.

Figure 2.

With the presence of one or more of four predictive radiographic features (rib penciling, vertebral rotation, vertebral wedging, and atypical location), there is a higher probability of a dystrophic curve pattern.

Table 1

Nine Radiographic Characteristics of Dystrophic Deformity in Neurofibromatosis Type 1^{*}

Characteristics	% incidence
Rib penciling	62
Vertebral rotation	51
Posterior vertebral scalloping [^]	31
Vertebral wedging	36
Spindling of transverse processes	31
Anterior vertebral scalloping [^]	31
Widened interpedicular distance	29
Enlarged intervertebral foramina [^]	25
Lateral vertebral scalloping [^]	13

^{*}From Durrani AA, Crawford AH, Choudry SN, et al. Spine 2000

[^]For this study, anterior/posterior/lateral scalloping and enlarged intervertebral foramina were considered as one parameter.

Table 2**Modified Durrani Criteria for Assessment of Inter-Rater Reliability**

Characteristics
Rib penciling
Vertebral rotation
Vertebral scalloping (anterior/ lateral/ posterior)
Vertebral wedging
Spindling of transverse processes
Short sharp angular curve ^{**}
Widened interpedicular distance
Atypical location ^{**}

^{**} Additional criteria compared to Durrani et al.

Table 3

Accuracy of Radiographic Prediction of Dystrophic Curves

Reader	Rated Nondystrophic	Rated Dystrophic	Total # of Reads
1	47 (39%)	75 (61%)	122
2	45 (37%)	77 (63%)	122
3	40 (33%)	82 (67%)	122
4	48 (39%)	74 (61%)	122
5	67 (55%)	55 (45%)	122
<i>OVERALL</i>	247 (40%)	363 (60%)	610
ACTUAL	39 (32%)	83 (68%)	122

Table 4

Agreement among Observers for Dystrophic Diagnosis and Radiographic Features

Characteristic	Fleiss' kappa
Dystrophic diagnosis	0.61
Vertebral wedging	0.62
Sharp short angular curve	0.60
Vertebral rotation	0.59
Spindling of transverse processes	0.42
Rib penciling	0.41
Atypical location	0.28
Widened interpedicular distance	0.18
Vertebral scalloping	0.14

Table 5

Radiographic Features Used by Readers to Predict a Dystrophic Curve Pattern

Characteristic	% Observed in all 610 readings	% Observed in x- rays deemed dystrophic by a given reader	% Observed in x- rays deemed nondystrophic by a given reader	P-value
Vertebral wedging	62%	91%	19%	<0.0001
Vertebral rotation	61%	89%	20%	<0.0001
Short sharp angular curve	53%	84%	6%	<0.0001
Rib penciling	43%	63%	13%	<0.0001
Vertebral scalloping	41%	58%	15%	<0.0001
Widened interpedicular distance	36%	55%	9%	<0.0001
Atypical location	22%	35%	4%	<0.0001
Spindling of transverse processes	15%	23%	3%	<0.0001

Table 6

Radiographic Features Predictive of a Dystrophic Curve Pattern

Characteristic	% Observed in all 610 readings	% Observed in truly dystrophic x-rays (Sensitivity)	% Observed in truly nondystrophic x-rays (1 - Specificity)	P-value	Relative Risk* (95% CI)
Vertebral wedging	62%	76%	31%	<0.0001	2.5 (2.0–3.1)
Vertebral rotation	61%	76%	29%	<0.0001	2.6 (2.1–3.3)
Short sharp angular curve	53%	65%	25%	<0.0001	2.6 (2.0–3.3)
Rib penciling	43%	54%	18%	<0.0001	3.0 (2.2–4.2)
Vertebral scalloping	41%	47%	28%	<0.0001	1.7 (1.3–2.2)
Widened interpedicular distance	36%	44%	20%	<0.0001	2.3 (1.7–3.1)
Atypical location	22%	30%	7%	<0.0001	4.5 (2.6–7.7)
Spindling of transverse processes	15%	18%	8%	0.0011	2.2 (1.3–3.7)

Table 7

Odds Ratios for Radiographic Features Predictive of a Dystrophic Curve Pattern

Characteristic	Wald Chi Square	P-value	Odds Ratio (95% CI)
Vertebral wedging	12.5	0.0004	2.4 (1.5–3.8)
Vertebral rotation	20.3	<0.0001	3.0 (1.9–4.8)
Short sharp angular curve	0.063	0.80	
Rib penciling	13.4	0.0003	2.4 (1.5–3.9)
Vertebral scalloping	0.69	0.41	
Widened interpedicular distance	0.35	0.55	
Atypical location	11.1	0.009	3.0 (1.6–5.7)
Spindling of transverse processes	0.04	0.85	