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Does the Presence of Dystrophic Features in Patients With Type 1 Neurofibromatosis and Spinal Deformities Increase the Risk of Surgery?

Marios G. Lykissas, MD, PhD,* Elizabeth K. Schorry, MD,† Alvin H. Crawford, MD,* Sean Gaines, DO,* Margaret Rieley, MD,† and Viral V. Jain, MD*

Study Design. Retrospective chart and radiographical review.

Objective. To present the demographics of patients with scoliosis and neurofibromatosis type 1 (NF-1), to record the incidence of dystrophic features, and to determine whether the presence of dystrophic features increase the risk of surgery in patients with NF-1 and associated spinal pathology.

Summary of Background Data. The most common of the osseous complications of NF-1 is spinal deformity, occurring in 10% to 30% of individuals with NF-1. Many of these patients will eventually require surgery for curve progression, which makes study of demographics and identification of features predicting the need for surgery essential in this patient population.

Methods. A retrospective review was performed in patients with NF-1 and spinal deformities, followed in a multidisciplinary neurofibromatosis center. A subset of 56 patients with complete radiographical evaluation was reviewed for identification of risk factors for spine surgery.

Results. One hundred thirty-one patients from a population of 694 patients with NF-1 (19%) had scoliosis. Mean age at diagnosis of scoliosis was 9 years (range; 1–17 yr). Scoliosis and need for surgery were equally distributed between males and females. In the group of 56 patients, 63% had 3 or more dystrophic features. The presence of 3 or more dystrophic features was the strongest predictor of the need for surgery (odds ratio = 14.34; $P < 0.001$). Individual features most predictive of need for surgery were the presence of vertebral scalloping (odds ratio = 13.19; $P < 0.001$) followed by the presence of dural ectasia (odds ratio = 6.38; $P = 0.005$). Patients with no dystrophic features were unlikely to progress to need for surgery.

Conclusion. Scoliosis and need for surgery were equally distributed between males and females. The presence of 3 or more dystrophic features was highly predictive of the need for surgery, with the most significant individual predictors being vertebral scalloping and dural ectasia. A combination of radiographical and MRI features can be used to predict need for spinal surgery.

Key words: neurofibromatosis, spinal deformity, scoliosis, paraspinal tumors, surgery prediction.

Level of Evidence: 3

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Neurofibromatosis type 1 (NF-1), or peripheral neurofibromatosis, is a relatively common genetic disorder affecting about 1 in 3000 individuals.[1] The primary pathological process is thought to be due to activation of the Ras pathway. The features of the disorder are quite diverse and can include dermatologic, cognitive, tumorigenic, and osseous.[2] Osseous complications of NF-1 can be categorized as either focal or generalized.[2] Known focal osseous complications include long bone dysplasia with pseudarthrosis, sphenoid wing dysplasia, nonossifying fibromas of long bones, chest wall deformities (pectus excavatum), and focal, short-segmented scoliosis. These focal complications occur in up to 38% of patients with NF-1.[3] Generalized features include overall shorter stature, larger head circumference, and decreased bone mineral density. Osteopenia or osteoporosis has been reported in up to 50% of children and adults with NF-1, with mean bone mineral density about 1 standard deviation below that of the general population.[4,5]

The most common of the osseous complications of NF-1 is spinal deformity, occurring in 10% to 30% of individuals with NF-1.[6–8] Many of these patients will eventually require surgery for curve progression, which makes study of demographics and identification of features predicting the need for surgery essential in this patient population.[8] Based on plain radiographs, it has been documented that 2 distinct types of scoliotic curves occur in NF-1: a dystrophic curve that is highly likely to progress, and a nondystrophic curve similar to that seen in idiopathic scoliosis.[8,9] The purpose of

From the *Divisions of Orthopaedic Surgery and †Human Genetics, Cincinnati Children's Hospital Medical Center, Cincinnati, OH.

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Address correspondence and reprint requests to Alvin H. Crawford, MD, Cincinnati Children's Hospital Medical Center, Division of Orthopaedic Surgery, 3333 Burnet Ave, MLC 2017, Cincinnati, OH 45229; E-mail: Alvin.Crawford@cchmc.org

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this study was to present the demographics of patients with scoliosis and NF-1, to record the incidence of dystrophic features, and to determine whether the presence of dystrophic features increases the risk of surgery in patients with NF-1 and associated spinal pathology.

MATERIALS AND METHODS

After obtaining institutional review board approval, the medical records of patients with the diagnosis of NF-1 followed in a multidisciplinary neurofibromatosis center between 1990 and 2008 were retrospectively reviewed. The diagnosis of NF-1 was established when at least 2 of the most commonly presenting features of the disease, as defined by the 1987 Consensus Development Conference of the National Institutes of Health, were present.[10]

From a clinic population of 694 patients meeting diagnostic criteria for NF-1, 131 (19%) were found to have scoliosis curvature of at least 10°. Diagnosis of scoliosis was usually suspected initially on clinical examination and confirmed radiographically. The medical records of 125 patients with NF-1 and associated scoliosis and a minimum follow-up of 2 years were reviewed. Data were collected on age at diagnosis of scoliosis, sex, race, degree of curvature at presentation, location of curve, presence of kyphosis, follow-up, and need for surgical intervention. Inclusion criteria were: (1) presence of a scoliotic curve of 15° or greater and (2) complete imaging available for analysis (including both plain films and magnetic resonance images [MRI]).

The records, photographs, and imaging data of 56 patients who met the inclusion criteria were evaluated in detail by 2 of the authors for evidence of dystrophic features. Plain radiographs and MR images scans were analyzed for presence of characteristics of dystrophic deformity, including: (1) rib penciling (width of the rib smaller than narrowest portion of the second rib)[11]; (2) vertebral rotation of grade 3+ as measured by the Moe-Nash method; (3) vertebral scalloping (distance between the vertebral margin and deepest portion of the scalloped vertebra more than 3 mm in the thoracic spine or 4 mm in the lumbar spine); (4) vertebral wedging in either sagittal or coronal plane; (5) spindling of the transverse processes (loss of 50% from the height of the transverse process measured halfway between the lateral edge of the vertebral body and tip of the transverse process as compared with the contralateral normal side or uninvolved vertebra above or below in the same anatomic segment of spine); (6) focal, short-segmented curve involving 6 or less vertebrae; (7) dural ectasia seen on MR image; and (8) paraspinal tumors or plexiform neurofibromas located close to the scoliosis curve on MR image.

Patients with 3 or more of these features were defined as having a dystrophic curve. Any correlation of presence of these features with prediction of surgical intervention was investigated.

STATISTICAL ANALYSIS

All variables were dichotomized, such that either the dystrophic feature was present or not. For each separate dystrophic feature, both relative risk ratios and odds ratios were calculated to determine whether the presence of a dystrophic feature increased the likelihood of needing spine surgery in patients with NF-1. Relative risk (p/q) is the ratio of the probability of patients with a dystrophic feature needing surgery (p) over the probability of patients without that dystrophic feature needing surgery (q). The odds ratio is the probability of patients with a dystrophic feature needing surgery over not needing surgery $[p/(1-p)]$ relative to the probability of patients without a dystrophic feature needing surgery over not needing surgery $[q/(1-q)]$. The statistical significance of these differences in proportion was calculated using the Fisher exact test. A multivariate logistic regression was performed including all of the dystrophic features as predictors of the need for surgery to determine which features were the most significant predictors of surgery. Statistical significance was set at $P < 0.05$ for all tests.

RESULTS

Of the 125 patients with NF-1 associated with scoliosis, demographics were representative of the racial distribution seen in our overall clinic population, with 86% Caucasian, 11% African American, and 3% other (Table 1). Males and females were close to equally represented, with 54% of the group being female. Mean age at diagnosis of scoliosis was 9 years (range; 1–17 yr). Eighteen patients (14%) had onset of scoliosis before age 7 years, 75 (60%) between age 7 and 12 years, and 32 patients (26%) had onset of scoliosis after age 12 years (Figure 1). The earlier the onset of spinal deformity, the more likely the need for surgical intervention. Patients presenting after age 12 years with spinal deformity were very unlikely to require surgery. Patients were followed for a median of 7 years after diagnosis of scoliosis (range; 2–30 yr). Curve magnitude at presentation was in the range of a Cobb angle of 10° to 120° (mean, 28°). Scoliotic curve progressed under observation by a mean of 26° (range, 5°–58°). Among 46 patients (37%) requiring surgery, 22 (48%)

TABLE 1. Demographic Data of 694 Patients With NF-1

Number of Patients in NF-1 Database	694
Total number of patients with scoliosis	131 (19%)
Total number of patients with scoliosis and follow-up ≥ 2 yr	125 (18%)
Sex of patients with scoliosis	54% female
Race	86% Caucasian
Median of follow-up	7 yr (range, 2–30 yr)
Age at diagnosis of scoliosis	9 yr (range, 1–17 yr)
Patients requiring surgery	46 (37%)
Scoliosis onset before age 7 yr	14%
Percent onset age 7–12 yr	60%
Percent onset after age 12 yr	26%

NF-1 indicates neurofibromatosis.

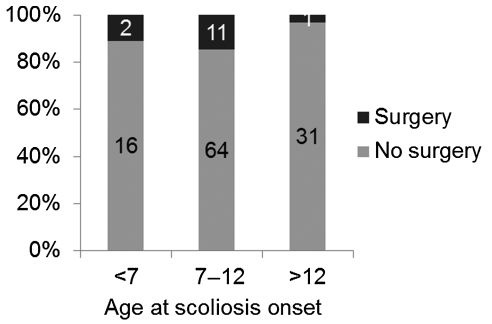

Figure 1. Age at scoliosis presentation and need for surgery.

were females. Primary curves were mostly located in thoracic (55%) and thoracolumbar (37%) regions, with 10% primarily affecting cervical vertebrae and 6% involving primarily lumbar vertebrae. Table 2 shows the relative risks for spine surgery on the basis of plain radiographical findings in all 125 patients with scoliosis and minimum follow-up of 2 years.

Among 56 patients with a curve of more than 15° and complete radiographical imaging available for analysis, 35 (63%) had evidence of paraspinal tumors on MR image (Figure 2A–D; also see Supplemental Digital Content Figure 2E and F, available at http://links.lww.com/BRS/A774) and 21 patients (38%) had no paraspinal tumors. Dural ectasia was recorded in 21 patients (38%). Evidence of 3 or more dystrophic features was manifested in 35 of the 56 patients (63%). Six patients (13%) had 1 or 2 dystrophic features, whereas in 15 patients (24%) no dystrophic features were noticed (Figure 3D–G; also see Supplemental Digital Content Figure 3A, B, and C, available at http://links.lww.com/BRS/A775). A focal curve, characterized by a short-segmented and sharply angulated deformity, was recorded in 29 of the 56 patients (52%) (Figure 4A–C; also see Supplemental Digital Content Figure 4D, available at links.lww.com/BRS/A776). Table 3 shows the incidence of dystrophic features as determined by the combination of plain radiographs and MR image. Cervical kyphosis of 17° was present in 1 patient (2%), thoracic kyphosis in 4 (3%) (range, 56°–100°), whereas thoracic lordosis (hypokyphosis) was noticed in 10 patients (18%).

A total of 31 of the 56 patients (55%) underwent posterior spinal fusion with or without anterior release and fusion. Twenty-four of the 31 patients (77%) had paraspinal neurofibromas; 7 had no evidence of paraspinal tumors on MR image or at surgery (23%). Statistical analysis revealed that patients with NF-1 associated with paraspinal tumors had a 4.36 times greater odds of requiring surgery than patients without evidence of paraspinal tumors, which was found to be statistically significant ($P = 0.014$) (Table 4). The relative risk for spine surgery in patients with paraspinal tumors was 2.12. Surgery was required in 22 patients (71%) with focal, short-segmented curves. Patients with NF-1 in whom imaging evaluation showed a focal, short-segmented curve had a significant 6.29 times greater odds of requiring surgery than patients without a focal curve ($P = 0.003$).

TABLE 2. Relative Risks for Spine Surgery Based on Plain Radiographical Findings in 125 Patients With NF-1 and Scoliosis

	No Surgery	Surgery	Relative Risk (95% CI)
No vertebral scalloping	48 (84%)	9 (16%)	3.45 (1.82–6.52)
Vertebral scalloping	31 (46%)	37 (54%)	
No vertebral spindling	66 (73%)	24 (27%)	2.36 (1.54–3.61)
Vertebral spindling	13 (37%)	22 (63%)	
No vertebral wedging	51 (84%)	10 (16%)	3.43 (1.87–6.29)
Vertebral wedging	28 (44%)	36 (56%)	
No vertebral rotation	52 (78%)	15 (22%)	2.39 (1.44–3.96)
Vertebral rotation	27 (47%)	31 (53%)	
No rib penciling	60 (73%)	22 (27%)	2.08 (1.33–1.59)
Rib penciling	19 (44%)	24 (56%)	
No focal-short segmented curve	49 (83%)	10 (17%)	3.22 (1.76–5.90)
Focal-short segmented curve	30 (45%)	36 (55%)	
<3 dystrophic features	45 (85%)	8 (15%)	3.50 (1.78–6.87)
≥3 dystrophic features	34 (47%)	38 (53%)	

*$P < 0.05$, statistically significant.

CI indicates confidence interval; NF-1, neurofibromatosis.

The relative risk for spine surgery in patients with focal, short-segmented curve was 2.76. Of the 31 curves requiring surgery, 27 (87%) were characterized by the presence of 3 or more dystrophic features. Patients with less than 3 dystrophic features required surgery in only 13% of the cases (4 patients). Patients with NF-1 who had 3 or more dystrophic features had a significant 14.34 times greater odds of requiring surgery than patients with less than 3 dystrophic features ($P < 0.001$). The relative risk for spine surgery in patients with 3 or more dystrophic features was 3.54. Seventeen of 21 patients with dural ectasia (81%) underwent surgery for correction of spinal deformity. Patients with dural ectasia had a significant 6.38 times greater odds of requiring surgery than patients without dural ectasia ($P = 0.005$). The relative risk for spine surgery in patients with dural ectasia was 3.15.

Twenty-five patients (45%) did not meet indications for spine surgery. Among these, paraspinal tumors were identified in 11 patients (44%) and dural ectasia in 4 patients (16%). A focal, short-segment deformity was recorded in 7 curvatures treated conservatively (28%). Nonsurgical management was also recommended in 8 patients (32%) with 3 or more dystrophic features.

When a multivariate logistic regression was performed, including all of the dystrophic features as predictors of the

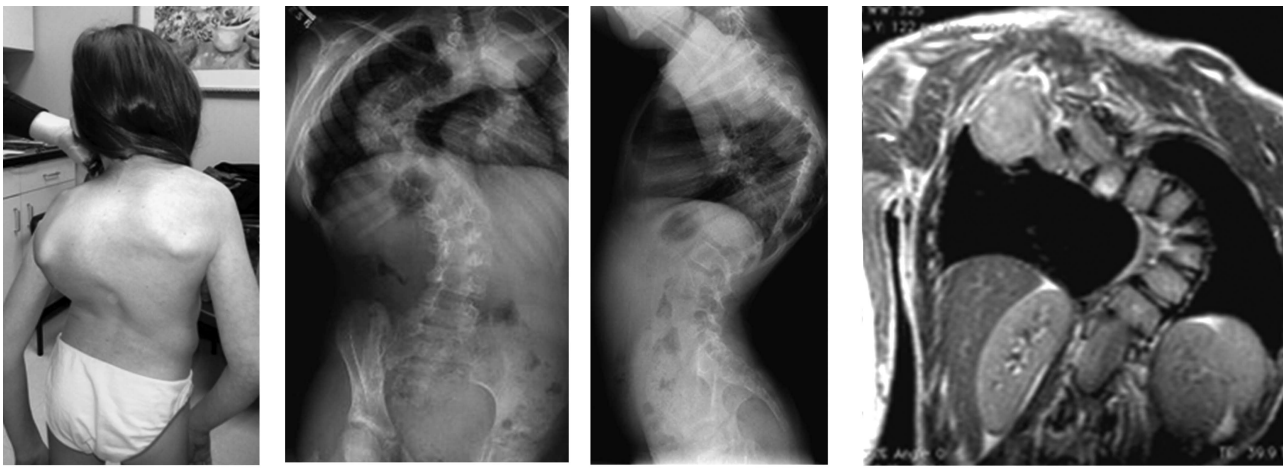

Figure 2. Photograph of a 9-year-old female patient with NF-1 and severe kyphoscoliosis of the thoracic spine (**A**). Posteroanterior (**B**) and lateral (**C**) plain radiographs reveal a focal, sharply angulated curve measuring approximately 120°. Coronal MR images of the spine show the presence of multiple paraspinal neurofibromas (**D**). MRI indicates magnetic resonance imaging; NF-1, neurofibromatosis-1.

need for surgery (Table 4), the presence of vertebral scalloping was the most significant predictor ($P = 0.044$) followed by the presence of dural ectasia ($P = 0.14$). With a sample size of 56 patients, the Fisher exact test had 80% power at an alpha level of 0.05 to detect differences greater than 32% to 40% between the proportion of patients with a dystrophic feature needing surgery and not needing surgery. For transverse process spindling, the difference in proportion was 23% ($P = 0.079$), and for rib penciling, the difference in proportion was 25% ($P = 0.087$), suggesting that the test was underpowered to detect these differences.

DISCUSSION

Study of demographics and identification of features predicting the need for surgery in patients with NF-1 and associated scoliosis is considered essential because spinal deformity is the most common osseous complication of NF-1 and many of these patients will eventually require surgery for curve progression. In this study, 131 patients from a population of 694 patients with NF-1 (19%) had scoliosis. In the majority of these patients (60%), scoliosis was diagnosed between 7 and 12 years of age. Patients presenting after age 12 years were very unlikely to require surgery. Sixty-three percent of patients with a complete radiographical evaluation had paraspinal tumors, 55% vertebral scalloping, 52% wedging of the vertebral body, 52% had a focal, short-segmented curve, 43% vertebral rotation, 38% dural ectasia, 34% rib penciling, and 29% had transverse process spindling. Sixty-three percent of the patients had 3 or more dystrophic features, whereas in 24% no dystrophic features were recorded. The presence of 3 or more dystrophic features was the strongest predictor of the need for surgery. Individual features most predictive of need

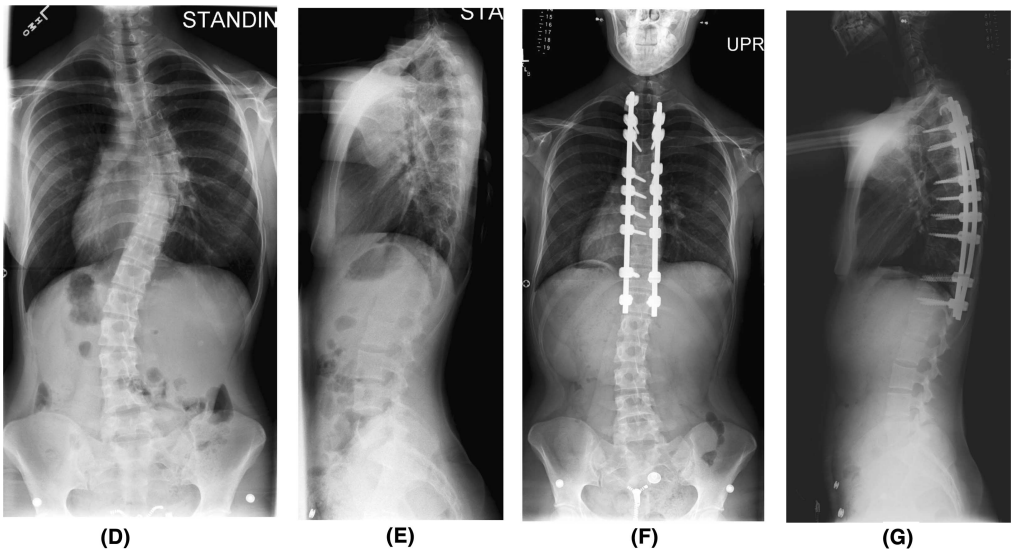

Figure 3. Posteroanterior (**D**) and lateral (**E**) scoliosis films at age 23 demonstrate significant progression of the curve. Posteroanterior (**F**) and lateral (**G**) standing films of the spine immediately after treatment with instrumented posterior spinal fusion from T3 to T12, 3A, B, and C are available as Supplemental Digital Content.

Figure 4. Posteroanterior (**A**) and lateral (**B**) scoliosis films and 3-dimensional CT scan (**C**) of the spine of a 12-year-old female patient with NF-1 and focal, short-segmented curve. CT indicates computed tomography; NF-1, neurofibromatosis-1.

for surgery were the presence of vertebral scalloping followed by the presence of dural ectasia.

The fact that not all patients had complete imaging may have underestimated the presence of some of the dystrophic features, especially tumors and dural ectasia. However, the subset of 56 patients with complete imaging available for analysis is considered the largest in the literature and valid information can be drawn regarding the incidence of dystrophic features and predictors of spine surgery in this patient population. Moreover, this study was underpowered to detect differences in some dystrophic features (transverse process spindling and rib penciling). These differences would likely have been statistically significant in a larger sample. These limitations highlight the fact that additional studies, including a prospective study of the natural history of spinal abnormalities in NF-1, are needed, and are currently in progress with this group.

Published reports of prevalence of scoliosis in NF-1 clinic populations have varied from 10% to 30%.[6–8] In our multidisciplinary clinic population, 19% of 694 patients with NF-1 had a scoliotic curve of greater than 10°. This was likely an overestimate of the true prevalence because our clinic is known to have specific interest in scoliosis. When corrected for 18 patients who were referred from outside our usual 3-state region, the prevalence of scoliosis in our NF-1 population was 16%. The sexes were equally represented. Clearly, the effects of NF-1 on the spine outweigh sex effects in this population.

TABLE 3. Incidence of Dystrophic Features in 56 Patients With Complete Imaging Available for Analysis

Dystrophic Features	No. of Patients	Incidence (%)
Vertebral scalloping	31	55
Rib penciling	19	34
Spindling of transverse process	16	29
Wedging of the vertebral body	29	52
Vertebral rotation	24	43
Dural ectasia	21	38
Paraspinal tumors	35	63
Focal, short-segmented curve	29	52

Traditionally, the term dystrophic scoliosis is used to describe thoracic and/or lumbar curves that have, at the time of diagnosis, more than 3 dystrophic features (as identified on plain radiographs). The concept of modulation refers to the ability of a spinal deformity to transform by acquiring various dystrophic features, and was found to be strongly associated with the presence of radiographical dystrophic features.[9] Of interest, Durrani *et al*[9] found that short-segmented curves were not statistically associated with modulation. In contrast, we demonstrated that a focal, short-segmented curve was highly predictive of need for surgery; although we did not look specifically at modulation. The article by Durrani *et al*[9] was based solely on findings from plain films. However, modulation may be present in young patients without any evidence of dystrophic features on radiographs, thus, MR image at presentation is valuable in classification of the curve and medical decision making.

More recent MRI studies have questioned the theory of modulation and highlighted the association of spinal deformities with paraspinal tumors and dural ectasia.[12] Patients with radiographically labeled nondystrophic curves have been found to have significant dysplastic changes on MR image. In this study, the relative risk for spine surgery was similar between the subset of patients with complete imaging and patients who had been evaluated only with plain radiographs, which may question the additional information obtained from MRI. However, multivariate logistic regression revealed that the presence of dural ectasia, which is a purely MRI finding, was the second most significant predictor of the need of surgery. Therefore, we recommend characterization of the curve as dystrophic or not based on a combination of MRI and radiographical findings. MRI findings of dural

TABLE 4. Odds Ratios and Relative Risks for Spine Surgery in Patients With Complete Imaging

	No Surgery	Surgery	Relative Risk (95% CI)	Odds Ratio (95% CI)	Fisher Exact *P* Value	Multivariate Logistic Regression *P* Value
No vertebral scalloping	19 (76%)	6 (24%)	3.93 (1.86–8.52)	13.19 (3.15–60.19)	<0.001*	0.044*
Vertebral scalloping	6 (19%)	25 (81%)				
No vertebral spindling	21 (53%)	19 (48%)	2.10 (0.88–6.69)	3.32 (0.79–14.86)	0.079	0.19
Vertebral spindling	4 (25%)	12 (75%)				
No vertebral wedging	19 (70%)	8 (30%)	3.40 (1.59–7.86)	9.10 (2.33–38.04)	<0.001*	0.39
Vertebral wedging	6 (21%)	23 (79%)				
No vertebral rotation	19 (59%)	13 (41%)	2.38 (1.11–5.84)	4.39 (1.20–16.73)	0.015*	0.87
Vertebral rotation	6 (25%)	18 (75%)				
No rib penciling	20 (54%)	17 (46%)	2.05 (0.92–5.66)	3.29 (0.86–13.26)	0.087	0.35
Rib penciling	5 (26%)	14 (74%)				
No focal, short-segmented curve	18 (67%)	9 (33%)	2.76 (1.34–6.01)	6.29 (1.70–24.36)	0.003*	0.75
Focal, short-segmented curve	7 (24%)	22 (76%)				
No dural ectasia	21 (60%)	14 (40%)	3.15 (1.28–9.98)	6.38 (1.54–28.52)	0.005*	0.14
Dural ectasia	4 (19%)	17 (81%)				
No paraspinal tumors	14 (67%)	7 (33%)	2.12 (1.11–3.74)	4.36 (1.20–16.49)	0.014*	0.36
Paraspinal tumors	11 (31%)	24 (69%)				
<3 dystrophic features	17 (81%)	4 (19%)	3.54 (1.83–5.94)	14.34 (3.21–70.96)	<0.001*	…
≥3 dystrophic features	8 (23%)	27 (77%)				

**P < 0.05, statistically significant.*

CI indicates confidence interval.

ectasia and paraspinal tumors were added in the criteria used to classify the spinal deformity as dystrophic.

Dural ectasia is known to be associated with a variety of conditions including Marfan syndrome, Ehlers-Danlos syndrome, ankylosing spondylitis, and Loeys-Dietz syndrome. It is thought to arise from increased hydrostatic pressure that progressively expands the dural sac. It may lead to the development of characteristic morphological changes in the vertebral column, including enlargement of the spinal canal and neuroforamina with possible pseudomeningocele, cortical thinning of the pedicles and laminae, and bony erosion. The increased space for the spinal cord in severe deformities suggests that it may have a protective effect in preventing neuropathy. In our study, we found that dural ectasia was highly predictive of need for surgery, with a relative risk of 6.38 for surgery compared with patients without dural ectasia.

The presence of a combination of 3 or more dystrophic features on radiographs and MR image was highly predictive of the need for surgery. Plexiform neurofibromas are known to be quite common in the general NF-1 population, with 56% of patients having plexiforms when a whole body MRI is performed,[13] and were seen in close proximity to the spine in 69% of patients in our study requiring spinal surgery. Although certainly contributing to scoliosis in some cases, it is clear that paraspinal tumors are not the primary cause of dystrophic scoliosis in NF-1, as many of our patients without tumors (33%) also had severely dystrophic curves requiring surgery. Patients with NF-1 without dystrophic features and with no paraspinal tumors or dural ectasia were unlikely to progress to need for surgery.

Nondystrophic scoliosis is a common spinal deformity in patients with NF-1, and was seen in 24% of our patients. Clinical and radiographical findings, treatment, and complications are similar to those described for idiopathic scoliosis. However, patients with NF-1 and associated nondystrophic scoliosis are historically affected earlier in life, have a worse prognosis, and have a higher pseudarthrosis rate or failure to obtain spinal fusion after surgery than their idiopathic counterparts. Therefore, nondystrophic curves in NF-1 are not truly comparable with idiopathic scoliosis in the non-NF-1 population. In our series, only one patient with nondystrophic scoliosis required surgery.

To the best of our knowledge, this is the largest series of patients with NF-1 and spinal deformity, and the first to provide predictors of surgery. Although related to the already described prediction of modulation, it is a different parameter with more important clinical relevance. Another major advantage of this study is the fact that all patients were followed in the same neurofibromatosis center and treated by the same orthopedic surgeon. In the second largest series of

patients, described by Winter *et al*,[14] the patients were treated in 3 centers by different surgeons. Furthermore, the addition of MRI findings provides a new dimension that may complement previous studies describing dystrophic features based solely on plain radiographs.

CONCLUSION

This study confirms the existence of at least 2 distinct types of scoliosis in NF-1; the first being a smooth, nondystrophic curve similar to idiopathic scoliosis, and a second type with dystrophic changes that is more likely to progress. Scoliosis and need for surgery were equally distributed between males and females. The presence of 3 or more dystrophic features was highly predictive of the need for surgery, with the most significant individual predictors being vertebral scalloping and dural ectasia. Paraspinal tumors were associated with need for spine surgery although such tumors are common in NF-1 and many patients with tumors did not require surgery. Patients with NF-1 with nonfocal curves, no dystrophic features, and no paraspinal tumors are less likely to progress to need for surgery.

➢ Key Points

- ❑ This study confirms the existence of at least 2 distinct types of scoliosis in NF-1; the first being a smooth, nondystrophic curve similar to idiopathic scoliosis, and a second type with dystrophic changes that is more likely to progress.
- ❑ Scoliosis and need for surgery are equally distributed between male and female patients with NF-1.
- ❑ The presence of 3 or more dystrophic features is highly predictive of the need for surgery, with the most significant individual predictors being vertebral scalloping and dural ectasia.
- ❑ Patients with NF-1 with nonfocal curves, no dystrophic features, and no paraspinal tumors are less likely to progress to need for surgery.

Supplemental digital content is available for this article. Direct URL citations appearing in the printed text are provided in the HTML and PDF version of this article on the journal's web site (www.spinejournal.com).

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