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Disc and Vertebral Wedging in Patients With Progressive Scoliosis

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Summary: A retrospective longitudinal radiographic study of patients with progressive scoliosis was conducted to determine the relative amount of wedging between vertebrae and discs as a function of progression of the scoliosis curve, cause of the scoliosis, and anatomic curve region. Posteroanterior radiographs of 27 patients with idiopathic scoliosis and of 17 patients with scoliosis associated with cerebral palsy were studied. The amount of wedging of vertebrae and discs at the curve apex was measured by the Cobb method and expressed as a proportion of the curve's Cobb angle. On average, the relative amount of vertebral and disc wedging did not differ significantly between initial and follow-up radiographs made after progression of the scoliosis. In both groups of patients, the mean vertebral wedging was more than the disc wedging in the thoracic region; the converse was found in curves in the lumbar and thoracolumbar regions. The patients with scoliosis associated with cerebral palsy had curves that were longer and more commonly in the thoracolumbar and lumbar regions. The relative wedging did not change significantly with curve progression and did not appear to differ by diagnosis. In the management of scoliosis, including small curves, it should be recognized that both the vertebrae and discs have a wedging deformity. **Key Words:** Scoliosis—Vertebra—Wedge deformity—Natural history—Radiography.

The scoliosis deformity is three-dimensional and includes curvature of the spine in the coronal and sagittal planes with rotation in the axial plane (1). The largest component of the deformity is the lateral curvature in the coronal plane. It results from lateral wedging of both the vertebrae and discs (2,3), but the proportions of wedging that occur in these two anatomic structures is unknown. It has been suggested that the deformity begins in the discs, and that the vertebrae become more deformed as the scoliosis progresses (2). It is not known whether the relative proportion of vertebral and disc wedging depends on the cause (diagnosis) of the scoliosis, the anatomic level, or whether it changes with the progression of the curve.

Progression of the vertebral wedging component in skeletally immature patients may be attributed to mechanical modulation of vertebral growth, as described in the Hueter-Volkmann Law (4). Although this may seem intuitively plausible, experimental and clinical investigations have remained inconclusive as to the pathophysiology of the development of the wedge deformity in the vertebrae and discs in scoliosis. Taylor (2) found that growth in the height of discs of nonambulatory patients with cerebral palsy was less than that of normal age-matched controls, implying that reduced loading retarded growth. Gooding and Neuhauser (5) reported "tall vertebrae" in patients with paralysis and also in younger patients who had been treated surgically with posterior fusion of the spine. They argued that the relative unloading of the spine produced increased longitudinal growth of vertebrae.

The risk of scoliosis progression is greatest during the adolescent growth spurt for patients with idiopathic scoliosis and for patients with scoliosis associated with cerebral palsy. Lonstein and Carlson (6) retrospectively analyzed 727 patients with idiopathic scoliosis, following them until skeletal maturity or until progression of the

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curve, and reported that the risk of progression is most related to skeletal immaturity and larger scoliosis curve magnitude. In patients with neuromuscular scoliosis associated with cerebral palsy, progression of the curve is less predictable because of the variable onset of puberty, degree of spasticity, and ambulatory status. Miller et al. (7) retrospectively reviewed the scoliosis curve pattern, length, magnitude, and rotation in 43 patients with cerebral palsy with spastic quadriplegia, following them until the curve was 50°. Early onset of scoliosis and increased rotation of the curve were predictive of progression of the deformity.

We conducted this longitudinal radiographic study of patients with documented progressive scoliosis to determine the relative amount of wedging between vertebrae and discs for two different causes of the scoliosis (idiopathic, and scoliosis associated with cerebral palsy). Each patient was studied longitudinally with two radiographs to determine whether the relative amount of vertebral and disc wedging changed with progression of the scoliosis deformity, and whether the relative amount of vertebral and disc wedging differed for curves with the apex in different anatomic regions of the spine.

METHODS

Twenty-seven patients with idiopathic scoliosis and 17 patients with scoliosis associated with cerebral palsy were studied after we reviewed the clinical records and radiographs of patients with progressive scoliosis seen at two tertiary referral centers each serving populations of approximately 400,000 people. Patients' radiographs were included in this study if they had radiographically documented progression of untreated scoliosis (increase greater than 5° Cobb angle) and with radiographs having adequate quality for measurement of wedging angles. We selected two films for each patient: the earliest suitable radiograph and the latest subsequent follow-up radiograph. The largest curve of each patient was studied, and the radiographs were all made before any surgery. Patients were classified by the anatomic level of the curve apex; because of the relatively small number of thoracolumbar curves, these were grouped along with lumbar curves and were compared with the thoracic curves.

The degree of vertebra and disc wedging was measured from the posteroanterior radiographs by drawing a line across the superior and inferior endplates of each vertebra in the curve. The coordinates of two points on each line were digitized (GTCO Digitizer, Rockville, MD, U.S.A.) and were saved in a computer file. Custom software calculated the angle of each line from the horizontal, using these coordinates. The vertebral wedging was calculated by taking the difference in angle between the adjacent lines on a vertebra. Similarly, the amount of disc wedging was calculated from the difference between the angles of the two lines on each disc. In each curve, the apical vertebra plus two vertebrae above and two below (five vertebrae) and their adjacent discs were selected for analysis (Fig. 1). The apical vertebra was determined by a computer program that selected the vertebra with the maximum lateral deviation from the patient's spinal axis (the line joining the vertebral body centers of T1 and S1). Then the wedge angles for the vertebrae and discs were expressed as a proportion of the Cobb angle. For comparisons of wedging between vertebrae and discs, the mean of the two adjacent disc wedge angles was compared with that of the intervening vertebra.

Analysis of variance was used to determine whether the wedge angles of the vertebrae and the discs as a proportion of the Cobb angle differed by apex region grouping or by

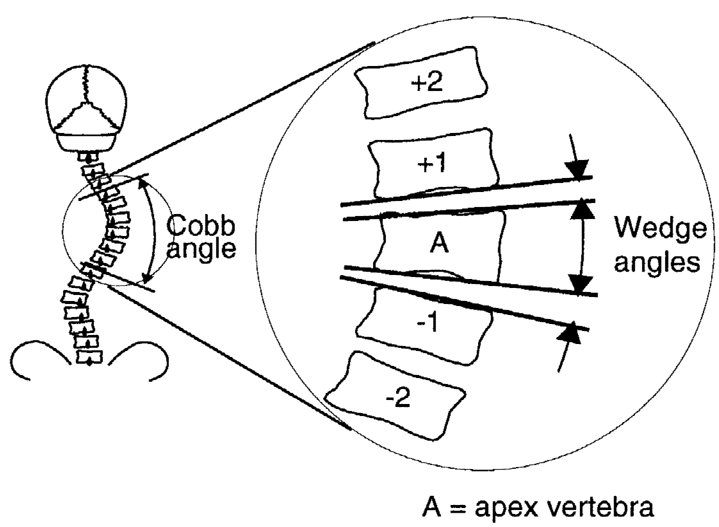

FIG. 1. Disc and vertebral wedge angles. Wedge angles were measured at apical vertebrae and discs, and at one and two levels above and below the apex.

diagnosis. To examine whether these proportions changed with curve progression, the mean individual differences were examined by the *t* test (null hypothesis was that the mean differences from first to second radiograph were zero). Also, the changes over time in the disc and vertebral wedging as a proportion of Cobb angle were examined by analysis of variance to determine whether they differed by the grouping factors diagnosis and curve apex region.

RESULTS

Among the 27 patients with idiopathic scoliosis, 18 had a curve with thoracic apex and 9 had a thoracolumbar or lumbar curve. Among the 17 patients with scoliosis associated with cerebral palsy 6 had a curve with a thoracic apex and 11 had a thoracolumbar or lumbar curve. Details of the patients and the measurements obtained are given in Tables 1 and 2.

A consistent finding in both groups of patients was that the disc wedge angle (as a proportion of Cobb angle) was less in thoracic curves than in the lumbar and thoracolumbar curves ($p < 0.01$). The mean vertebral wedging (as a proportion of Cobb angle) was observed to be greater in idiopathic thoracic curves than in the idiopathic curves below T11, but not in radiographs of patients with cerebral palsy (Table 3). The mean vertebral and disc wedging as a proportion of Cobb angle did not significantly change between the initial and follow-up radiograph in either diagnostic group of patients. Also, the relative proportions of disc and vertebral wedging within each apex level group did not change significantly with curve progression.

The wedging of both vertebrae and discs was greatest at the apex of the scoliosis deformity. The wedging of the apical vertebra was found to be greater relative to adjacent vertebrae in the patients with idiopathic scoliosis than the patients with scoliosis associated with cerebral palsy, because the average amount of wedging of the apical vertebra was 1.4 (idiopathic scoliosis) and 1.15 (cerebral palsy) times greater than the mean of the vertebrae immediately above and below the apex, and 3.5 (idiopathic scoliosis) and 2.1 (cerebral palsy) times greater the mean of the vertebrae two above and two below the apex. The patients with cerebral palsy had scoliosis curves involving more vertebrae. The distribution by curve apex was reciprocal, in that most curves in patients with idiopathic scoliosis were in the thoracic region (18 of 27 patients), whereas only 6 of 17 patients with cerebral palsy had thoracic curves (Table 1).

DISCUSSION

Among the patients with idiopathic scoliosis who had a thoracic major curve, the wedging at the apex was greater in the vertebrae than in the discs, whereas the opposite was generally found at the apex of the major lumbar and thoracolumbar scoliosis curves. No difference was found in the relative amount of apical vertebral and discal wedging between the patients with idiopathic scoliosis and those

TABLE 1. *Details of patients with scoliosis secondary to cerebral palsy*

		First radiograph				Second radiograph			
Patient no.	Apex	Age (y)	Cobb angle (°)	Vertebral wedge angle (°)	Discal wedge angle (°)	Age (y)	Cobb angle (°)	Vertebral wedge angle (°)	Discal wedge angle (°)
1	T12	8.5	35	−0.8	3.6	11.4	74	3.1	1.7
2	T11	10.9	32	3.0	2.2	13.0	47	0.5	6.0
3	L3	8.0	−16	−5.0	−5.2	8.7	−60	−10.0	−11.0
4	L2	5.3	−8	0.8	−3.4	13.8	−51	−10.3	−8.7
5	T6	7.4	44	4.8	5.1	13.7	49	13.4	8.0
6	L3	8.2	7	2.4	0.5	11.3	−37	−8.9	−3.8
7	L2	10.2	64	11.9	8.0	10.8	73	7.9	13.9
8	T12	8.4	30	1.1	3.4	12.6	55	7.1	4.8
9	L2	1.6	−34	−3.7	−1.5	2.1	−60	−10.0	−1.5
10	T12	16.4	17	1.2	4.6	19.1	39	1.0	6.3
11	T9	9.9	20	0.8	1.9	16.4	33	5.5	1.9
12	T8	5.6	25	4.5	−1.3	12.4	50	9.2	2.4
13	T12	9.6	−78	−14.9	−0.2	11.2	−105	−14.1	−3.0
14	L1	4.1	56	3.1	14.2	7.1	79	14.1	16.4
15	T12	7.3	36	6.1	−0.8	11.4	90	2.4	5.8
16	T9	3.1	16	0.1	0.9	8.3	63	3.7	8.5
17	T6	10.2	30	2.3	0.5	18.1	64	1.2	4.5
Mean		7.9	32.2	3.9	3.4	11.8	60.5	7.2	6.4
SD		3.4	18.8	3.9	3.4	4.1	18.6	4.5	4.2

All means are of absolute values. Age, patient age; Cobb angle, Cobb angle of largest curve; vertebral wedge angle, apex vertebra wedge angle; discal wedge angle, average of wedge angles of the discs adjacent to the apex vertebra. Cobb angle is negative for left concave curve; negative wedge angle = thinner on left.

TABLE 2. *Details of patients with idiopathic scoliosis*

Patient no.	Apex	First radiograph Age (y)	Cobb angle (°)	Vertebral wedge angle (°)	Disc wedge angle (°)	Second radiograph Age (y)	Cobb angle (°)	Vertebral wedge angle (°)	Disc wedge angle (°)
1	L2	11.0	−19	0.9	−5.6	14.3	−47	−14.0	−7.6
2	L2	11.6	−17	−3.2	−1.7	11.9	−31	−0.7	−6.1
3	L2	11.7	−13	0.3	−2.8	13.4	−29	−2.5	−5.4
4	T12	13.3	−19	−1.3	−3.5	14.8	−29	−5.6	−4.2
5	L2	9.4	−13	−4.2	−1.0	14.2	−31	−4.4	−5.2
6	L2	10.0	−13	0.2	−3.3	12.7	−31	−1.9	−8.7
7	T12	10.6	−18	−2.6	−3.8	11.5	−29	2.9	−7.7
8	T8	11.9	15	5.3	0.8	13.6	33	5.8	3.5
9	T8	11.7	25	3.0	1.6	13.3	38	8.0	0.8
10	T9	13.1	17	−1.3	2.8	13.6	25	2.4	1.8
11	T8	6.2	23	6.5	1.9	11.1	41	6.0	5.8
12	T8	7.0	15	−1.5	1.5	11.0	41	0.2	5.5
13	T9	13.0	16	6.2	0.1	14.2	33	2.3	5.5
14	T10	11.8	24	4.5	2.4	12.2	32	2.0	5.8
15	T4	12.0	−16	−5.2	−1.1	15.1	−41	−6.9	−11.6
16	T8	9.4	21	−0.7	−4.0	10.8	41	4.1	5.4
17	T9	8.9	21	5.1	2.5	13.7	63	15.4	6.6
18	T9	10.9	23	2.9	2.1	12.7	55	13.1	3.7
19	T8	13.3	27	9.2	5.1	10.8	40	9.2	7.3
20	T10	13.2	23	1.3	3.8	20.1	48	5.5	4.6
21	T8	10.4	27	11.0	2.7	12.2	58	15.4	5.1
22	T9	10.5	13	1.2	2.5	13.8	55	17.0	2.9
23	T8	12.0	43	3.4	7.6	13.3	57	3.3	7.9
24	L2	3.9	−13	−4.5	−1.0	9.6	−54	−10.8	−8.6
25	T8	11.2	8	2.3	−0.5	14.4	62	2.3	9.9
26	L2	15.7	−31	−5.7	−6.5	17.4	−43	−11.6	−5.6
27	T7	9.8	32	5.6	5.3	12.1	56	9.9	3.4
Mean		10.8	20.2	3.7	2.9	13.4	42.3	6.8	5.8
SD		2.4	7.3	2.6	1.9	2.1	11.4	4.9	2.4

All means are of absolute values. Age, patient age; Cobb angle, Cobb angle of largest curve; vertebral wedge angle, apex vertebra wedge angle; discal wedge angle, average of wedge angles of the discs adjacent to the apex vertebra. Cobb angle is negative for left concave curve; negative wedge angle = thinner on left.

with scoliosis associated with cerebral palsy. Also, the relative amount of wedging of the vertebrae and discs was not observed to change with progression of the scoliosis deformity. Therefore, the results of the current study do not support the hypothesis of Taylor (2) that the wedge deformity begins predominately in the discs and subsequently, with curve progression, the vertebrae become wedged. The division of wedging between vertebrae and discs in thoracic and lumbar curves may be related to the different disc thickness (relative to vertebral height) in these two anatomic regions. To take into account the changing curve magnitudes, we focused our analyses on the relative contributions of disc and vertebral wedging to the Cobb angle. Having done this, our study indicates that curve magnitude, amount of curve progression, elapsed time, and diagnosis were not significant contributors to the relative proportions of disc and vertebral wedging.

Because the discs are flexible, the measurements of disc wedging might change with patient positioning at radiography, and measures of both disc and vertebral wedging

TABLE 3. *Amount of apical vertebral and disc wedging (expressed as a percentage of the corresponding Cobb angle), broken down by curve region, and by measurements made from the initial and follow-up radiographs*

		Scoliosis associated with cerebral palsy: Thoracic (n = 6)	Thoraco-lumbar and lumbar (n = 11)	Idiopathic scoliosis: Thoracic (n = 18)	Thoracolumbar and lumbar (n = 9)
Initial radiograph	Vertebra	8.42% (5.5)	12.36% (12.8)	18.09% (15.4)	13.02% (13.8)
	Disc	5.02% (5.5)	15.61% (13.6)	8.77% (9.4)	17.99% (7.3)
Follow-up radiograph	Vertebra	11.85% (9.6)	12.93% (6.9)	15.06% (8.5)	13.03% (12.0)
	Disc	10.04 (4.3)	11.31% (6.9)	12.14% (6.0)	18.73 (4.9)

Values are the mean in each group (standard deviation in parentheses).

might be influenced by the radiographic projection used. These potential problems were probably minimized because all standing radiographs of patients with adolescent idiopathic scoliosis were made posteroanteriorly (PA) with a 72-inch (1.8 m) focus-to-film distance (FFD). For those patients with cerebral palsy who were radiographed sitting, the films were PA, with 72 inches FFD. For some of these patients, the procedure was an AP projection, 72 inches FFD, with the patient lying supine on the cassette, on the floor.

It has been recognized previously that even small scoliosis deformities include vertebral wedging. Xiong et al. (8) measured the wedging of vertebrae (in degrees) and discs (measured as the difference in disc height between convex and concave sides) in girls 13.3 to 19.3 years old. They reported that wedging of both the vertebrae and discs was present in small scoliosis curves, and interpreted these findings as showing a primary disturbance of vertebral and disc growth, because of extravertebral factors. In a cross-sectional study (9) of 86 skeletally immature patients with Cobb angle in the range 12–110°, radiographic measurements of the apical vertebra wedging showed a linear correlation with the magnitude of the Cobb angle. When the total wedging of all vertebrae in a curve was compared with the total disc wedging (9,10), there was a greater contribution of discal than vertebral wedging in smaller curves, but the ratio became almost equal in larger magnitude curves. In the current study, we evaluated only the apical and two adjacent vertebrae above and below and the corresponding discs, so it is possible that had we included the more flexible segments of the scoliosis curve, the discs might have been found to contribute more to the deformity. Perdriolle et al. (9) measured 13 anatomic specimens with a mean Cobb angle of 91° and observed that wedging was concentrated on the concave half of the vertebral endplates in all vertebrae from the major curves, creating a cuneiform-shaped vertebral body. The cuneiform shape was apparently a characteristic that developed by secondary remodeling in large curves in adults, and our measures of the younger clinical population would have minimal changes from adult bone remodeling that might predominate later in life.

Animal models of scoliosis also demonstrate a distribution of the wedge deformity between vertebrae and discs, but the method of producing the curvature is artificial. Stillwell (11) followed a progressive scoliosis deformity for up to 1½ years in immature monkeys after destabilization of the posterior elements of the spine. The disc angulation appeared before evidence of bony wedging, but eventually the disc angulation accounted for about half of the scoliosis deformity. Mente et al. (12) created a scoliosis deformity in a segment of the rat tail by imposing compressive forces and a lateral curvature. At the beginning of the experiment, 100% of the deformity was in the discs, but after 6 weeks of growth, 43% of the scoliosis curve was in the vertebrae, whereas 57% was still in the discs.

Because of differences in the natural history between idiopathic scoliosis and that associated with cerebral palsy, it is difficult to make comparisons based on chronological age. The age of the patients with idiopathic scoliosis at the time of the initial radiograph averaged 10.8 years, and it averaged 13.4 years at the time of the subsequent radiograph, whereas the patients with cerebral palsy averaged 7.9 years at the time of the initial radiograph and 11.8 years subsequently. There were also differences between the groups in the average curve magnitudes in the two radiographs (the patients with idiopathic scoliosis had smaller curve magnitudes). These factors may have confounded comparisons between these groups in the longitudinal aspects of this retrospective study.

The measurements in the current study were limited to frontal plane radiographs. Because there is also wedging in the sagittal plane associated with lordosis and kyphosis, the plane where maximum vertebral wedging occurs in a spine with scoliosis lies in an intermediate plane, depending on the relative amount of wedging in sagittal and frontal planes (13). The axial rotation of vertebrae in scoliosis may alter the apparent wedging seen in the frontal plane by bringing the sagittal plane wedging into evidence in the frontal projection. However, this was probably a small factor in this study because the sagittal wedging is generally small in magnitude relative to the amount of coronal plane wedging because of scoliosis at the curve apex. Furthermore, the amount of vertebral rotation is small relative to the 90° rotation required to make the sagittal plane wedging completely visible.

The measurement of vertebral wedging was done by a method similar to the measurement of Cobb angle, and therefore included similar technical errors, except that end vertebra selection did not contribute to measurement error here. Therefore, the error in wedging values would have an expected 95% confidence interval of 3.8°, based on the study of Morrissy et al. (14). This was confirmed by comparing measurements after repeated marking (two times) by each of three observers. Other errors result from variations in patient posture, and these would affect the measures of disc wedging but not of vertebral wedging.

The results of these and other studies suggest that vertebral body wedging occurs early in the development of a scoliosis deformity, and that both the discs and vertebrae develop an increasing wedge deformity in similar proportions with curve progression. The vertebrae generally showed a larger deformity than the discs in thoracic curves, and the discs developed a larger deformity in lumbar and thoracolumbar curves. The similarity between the disc/vertebra wedge ratio seen in both small and large curves, and in idiopathic scoliosis and scoliosis associated with cerebral palsy, suggests that the deformity occurs in both structures, and cannot be attributed to either structure alone. In the management of scoliosis, including small curves, it should be recognized that both the vertebrae and discs have a wedging deformity.

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