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U. Willers
E. E. Transfeldt
R. Hedlund

The segmental effect of Cotrel-Dubousset instrumentation on vertebral rotation, rib hump and the thoracic cage in idiopathic scoliosis

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U. Willers (✉)
Department of Orthopedic Surgery,
Huddinge University Hospital,
S-141 86 Huddinge, Sweden
Fax: +46-8-7114292

R. Hedlund
Department of Orthopedic Surgery,
Huddinge University Hospital,
Karolinska Institute, Stockholm, Sweden

E. E. Transfeldt
Twin Cities Scoliosis Spine Center,
Department of Orthopedic Surgery,
University of Minnesota,
Minneapolis, Minnesota, USA

Abstract The segmental effect of Cotrel-Dubousset instrumentation (CDI) on the spine and thoracic cage was investigated in 38 patients with adolescent idiopathic scoliosis by preoperative and postoperative postero-anterior and lateral radiographs and computed tomography from T1 to S1. Mean Cobb angle decreased by 67%. The T5–T12 kyphosis in the hypokyphotic patients increased on average by 8.4° ($P < 0.001$). Average preoperative as well as postoperative maximal vertebral rotation was located at the apex level, and was reduced from 19.0° to 14.3° ($P < 0.001$). All vertebrae between the upper and lower instrumented vertebrae were significantly derotated. Average derotation for the apical zone was 4.8° ($P < 0.001$), for the upper instrumented zone it was 2.5° ($P < 0.01$), and for the lower instrumented zone it was 2.6° ($P < 0.01$). Vertebral derotation was significantly higher in the apical zone than in the upper and lower instrumented zones. The apical rib hump index (RHi) decreased by 38% ($P < 0.001$) and the cumulative RHi for the five apical levels decreased by 34% ($P < 0.001$). The RHi for the two levels above and below the instrumentation each decreased by 20% (n.s.). No significant increase in sagittal or transverse rib cage diameter at any level was observed. The translation in the coronal plane of the apical vertebra of major right thoracic curves improved significantly ($P < 0.001$). The preoperative flexibility index of the major curve correlated positively ($r = 0.47$) with derotation at the apex level ($P < 0.01$). However, no correlation was found between flexibility index and reduction of RHi at the apex level. Vertebral derotation did not correlate with reduction in RHi at any level. The study shows that CDI results in a postoperative three-dimensional improvement of the spine and a limited improvement of the thoracic cage, with no tendency towards a worsened deformity at any level within or outside the instrumentation.

Key words Computed tomography · Cotrel-Dubousset instrumentation · Idiopathic scoliosis · Rib hump · Vertebral rotation

Introduction

Several studies have attempted to analyze the three-dimensional changes produced by CDI on the spine. In the horizontal plane the majority of studies have been limited to the apical vertebra; investigations into the effect on the thoracic cage have been limited to analysis of the rib hump [13, 14, 21, 24].

Recently, a study by Wood et al. suggested the effect of CDI on vertebral rotation may not be segmental, between vertebrae, but rather can occur "en bloc", with secondary forces applied to vertebral segments above and below the instrumented area resulting in decompensation of the spine [26].

Since the effect of instrumentation may vary between levels, and changes in the thoracic cage produced by CDI are poorly documented, we studied the segmental effect of CDI on the spine and the thoracic cage, within as well as outside the instrumented area.

Patients and methods

The study included 30 girls and 8 boys, mean age 14.4 years (range 11.2–21.5 years), with adolescent idiopathic scoliosis operated on using CDI at the Twin Cities Scoliosis Spine Center and the University of Minnesota. The average Risser sign was 2.9 (range 0–5).

There were 28 right thoracic curves and 10 double major curves with the thoracic curve to the right (Fig. 1). Using the King-Moe classification, the curve distribution was as follows: 1 type I, 16 type II, 13 type III, 5 type IV, and 3 type V curves [16]. The apical vertebra, the upper instrumented vertebra, and the lower instrumented vertebra were defined in each patient (Fig. 2). The apical zone was defined as the apical vertebra and the vertebra above and below it; the upper instrumented zone consisted of the two most cranial vertebrae within the instrumentation, and the lower instrumented zone consisted of the two most caudal vertebrae within the instrumentation. Standard CD and posterior fusion techniques were used, with an average of 9.8 (range 6–15) vertebral levels fused [12].

Preoperative and postoperative radiographic investigation included standing postero-anterior (PA) and lateral radiographs and segmental CT scans with axial cuts from T1 to the sacrum. The same investigations were repeated 7–10 days following surgery.

The coronal plane was analyzed by measuring the curve Cobb angle [11] and the apical vertebral translation. Coronal translation was measured on the PA radiograph as the distance from the midpoint of the apical vertebra to the midsacral line. On the CT scan the coronal translation was measured as the distance from the midpoint of the apical vertebra to the midpoint of the transverse diameter of the thoracic cage [1]. Coronal translation was determined for the apices of the major right thoracic curve and the upper and lower secondary curves. The curve flexibility index was calculated [8].

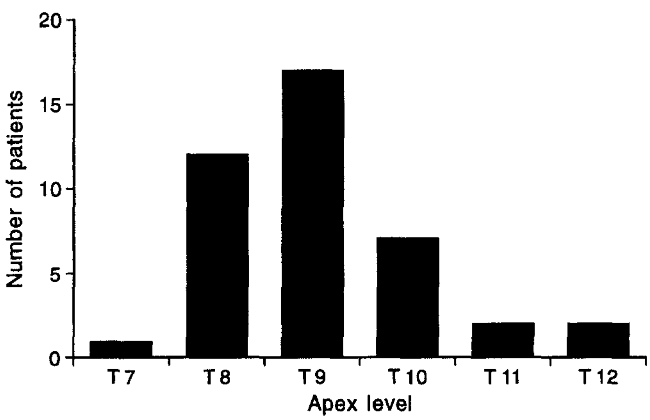

Fig. 1 Distribution of the apex level among 38 patients. The apex level given for the double major curves refers to the right thoracic or right thoracolumbar curve

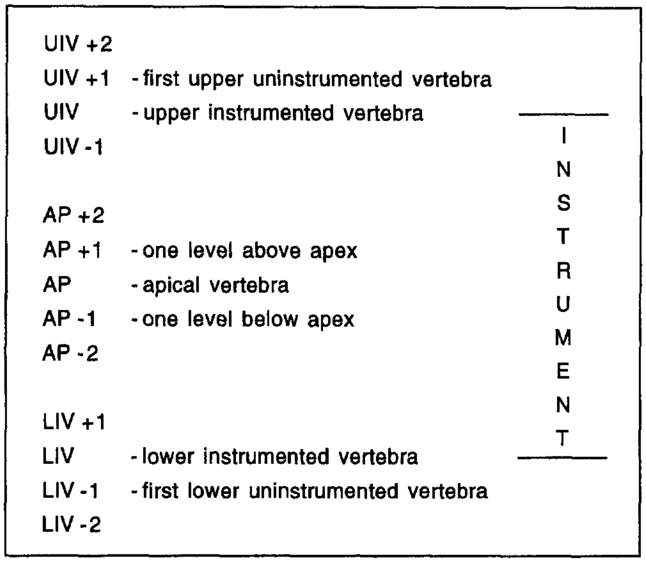

Fig. 2 Nomenclature used to describe the different levels of the spine within and outside instrumentation

Thoracic kyphosis and lumbar lordosis were measured, on standing lateral radiographs taken in the Moe position, between T5 and T12 and between L1 and L5, respectively [6, 8, 9].

In the segmental CT scans the sagittal and transverse diameters of the rib cage were measured at each level [1]. The sagittal diameter of the rib cage was defined as the perpendicular distance from the sternum to the anterior part of the spinal canal. The transverse diameter was defined as the distance between the most lateral parts of the rib cage on each side.

Relative vertebral rotation was calculated for each level using a modification of the method described by Aaro and Dahlborn [1]. To diminish measurement errors that may be caused by differences in position on the CT table, the vertebral rotation of each vertebral body was referenced to the rotation of T1, and not to the sagittal line. The derotation at each level was calculated and expressed as the difference between the preoperative and postoperative relative vertebral rotation.

The rib hump was measured at each level and was expressed as the rib hump index (RHi), which expresses the difference in rib prominence between the right and the left side divided by the distance to the spine [1]. In addition, a cumulative RHi was calculated for each patient for (a) the apical region, i.e., the sum of the RHi of the five apical levels and (b) for the upper and lower uninstrumented areas, i.e., the sum of the RHi of the two adjacent levels above and below the instrumentation, respectively.

Statistical analysis

The mean values of the preoperative and postoperative measurements were analyzed for statistical significance using the Student *t*-test for all 38 patients and separately for the 28 patients with right thoracic curves. To study the relationship between changes in the different planes, correlation coefficients were calculated. $P < 0.05$ was considered as statistically significant.

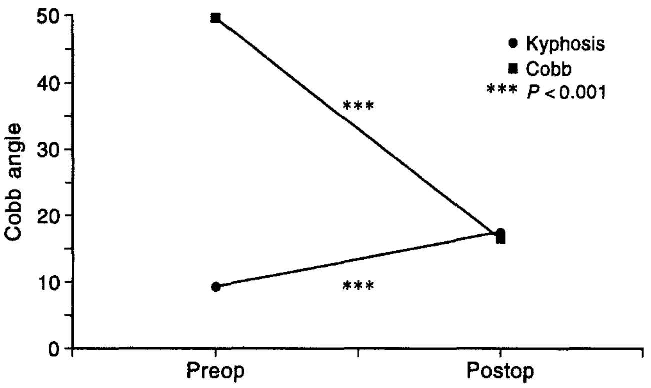

Fig. 3 Mean preoperative and postoperative Cobb angle in all patients and thoracic kyphosis T5–T12 in the 16 hypokyphotic (< 15°) patients

Results

All patients

In the 28 thoracic and 10 double major thoracolumbar curves the mean preoperative Cobb angle was 49.6° (range 35–81°). The average postoperative curve was 16.5° (range 3–34°), reflecting a 67% reduction ($P < 0.001$) (Fig. 3). The improvement in Cobb angle did not correlate with derotation or reduction in RHi postoperatively at any level. There was a weak negative correlation between the flexibility index and the preoperative apical vertebral rotation ($r = -0.36$; $P < 0.05$).

The preoperative flexibility index in the major curve was positively correlated ($r = 0.47$) with derotation at the apex level ($P < 0.01$). However, no correlation was found between flexibility index and reduction of RHi at the apex level. The mean postoperative Cobb angle correction of the major curve was 67% and the mean preoperative flexibility index of the same curve was 57%.

In the 16 patients with less than 15° of thoracic kyphosis, mean kyphosis increased from 8.9° (range 2–14°) to 17.3° (range 4–22°) postoperatively ($P < 0.001$) (Fig. 3). The preoperative lumbar lordosis of 47.6° (range 22–65°) decreased postoperatively to 45.6° (range 20–69°; n.s.).

In all curves a standard vertebral rotation was observed, with the vertebral bodies within the curve rotated towards the curve convexity. The average preoperative as well as postoperative maximal vertebral rotation was located at the apex level, and was reduced from 19.0° to 14.3° ($P < 0.001$). Derotation varied between 22% and 36% for the different levels between the upper instrumented vertebra and the lower instrumented vertebra, and was significant for all levels ($P < 0.05$).

Similarly, the slight vertebral rotation of the first vertebra above as well as below the instrumentation decreased postoperatively ($P < 0.05$) (Fig. 4).

The average derotation of the three apical vertebrae was 4.8° (26%) ($P < 0.001$). For the upper instrumented zone the derotation was 2.5° ($P < 0.01$), and for the lower instrumented zone it was 2.6° ($P < 0.01$). Thus, vertebral derotation was higher in the apical zone than in the upper and lower instrumented zones ($P < 0.05$). There was no statistical difference between the derotation of the two most cranial and the two most caudal vertebrae within the instrumentation.

The maximal rib hump was on average preoperatively as well as postoperatively located at the apex. The apical RHi decreased by 38% after CDI ($P < 0.001$). The cumulative RHi for the apical region decreased by 34% ($P < 0.001$) (Fig. 5). For the two levels above and the two levels below the instrumentation the decrease was 20% (n.s.).

Preoperative vertebral rotation and RHi were positively correlated at the apex level and in the upper part of

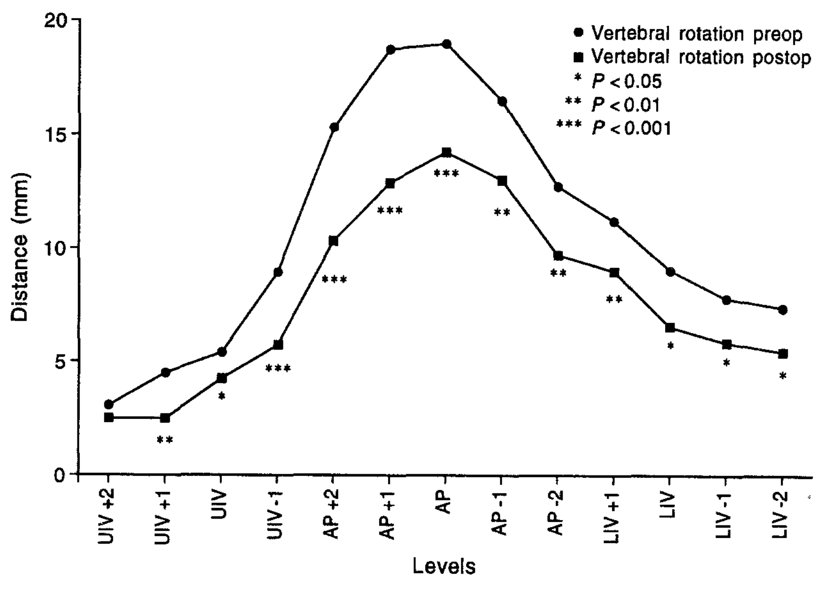

Fig. 4 Mean preoperative and postoperative vertebral rotation in all 38 patients in degrees. Note the statistically significant derotation at all but the uppermost level of the spine

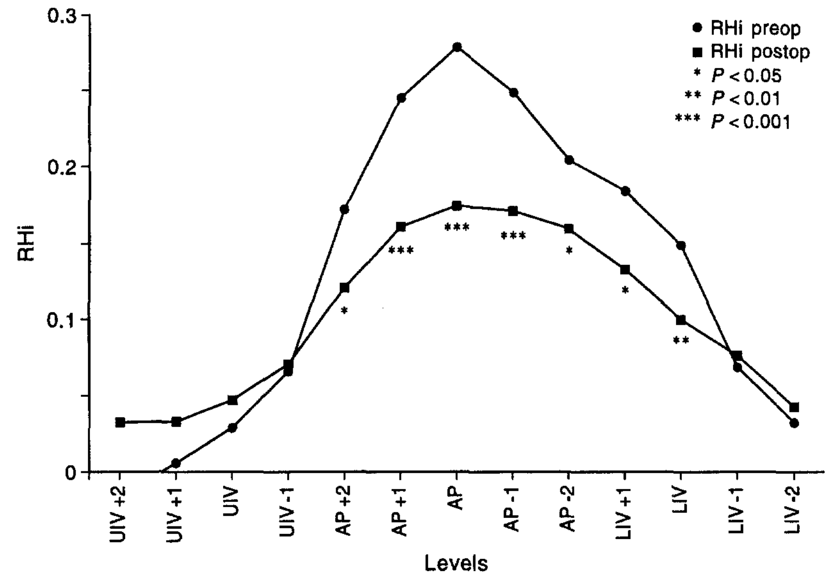

Fig. 5 Mean preoperative and postoperative RHi at all levels in all 38 patients. Significant changes were observed at all except the two uppermost levels of the instrumented part of the spine

Table 1 Segmental correlation coefficients between preoperative vertebral rotation and RHi in 38 patients with idiopathic scoliosis (*UIV* upper instrumented vertebra, *AP* apical vertebra, *LIV* lower instrumented vertebra)

Vertebral level	Correlation coefficient	*P*-value
UIV +1	0.27	0.17
UIV	0.17	0.36
UIV –1	0.40	0.01
AP +2	0.57	< 0.001
AP +1	0.46	< 0.01
AP	0.41	< 0.01
AP –1	0.12	0.49
AP –2	0.26	0.12
LIV +1	0.30	0.08
LIV	0.03	0.86
LIV –1	0.06	0.78

Table 2 Characteristics of the eight patients with an increased average vertebral rotation of the three apical vertebrae after CDI (*Th* thoracic)

Patient	Sex	Age (years)	King type	Anatomical classification	Cobb angle	Rotation increase
1	F	14.9	II	Th-right	81°	10.7°
2	M	14.7	III	Th-right	58°	3.0°
3	F	12.3	V	Th-right	48°	3.0°
4	F	13.0	III	Th-right	56°	1.3°
5	F	12.9	II	Double major	40°	1.0°
6	F	15.9	III	Th-right	41°	1.0°
7	M	14.6	II	Th-right	43°	0.3°
8	F	12.4	I	Double major	52°	0.3°

the thoracic curve, but not below the apex (Table 1). Among the patients as a whole, and separately for those with thoracic curves, vertebral derotation did not correlate with the reduction of RHi at any level.

On average there was no worsening of vertebral rotation or rib hump at any level within or outside the instrumentation. In eight patients, however, increased postoperative rotation was observed in the apical zone (Table 2).

Except for a slightly reduced postoperative sagittal diameter in the upper and lower part of the instrumentation, and a decreased transverse diameter at the apex level, no significant changes in diameter were observed (Fig. 6). Furthermore, there was no increase in the sagittal diameter in the hypokyphotic patients, in whom a significantly improved thoracic kyphosis was observed, and the sagittal diameters remained unchanged at all levels in the 50% of patients with the smallest preoperative sagittal diameter.

Translation in the coronal plane, as measured both on radiographs and on CT scans, improved significantly at the apex of the major right thoracic curve, by 81% and 60%, respectively. Similarly, in the secondary curves the translation of the apical vertebrae improved as measured by CT, but non-significantly as measured on PA radiographs (Fig. 7). Reduction of apical coronal translation correlated (r = 0.44) with postoperative improvement in the Cobb angle ($P < 0.01$). At the apical level no correlation was found between the reduction of coronal translation on the one hand and the reduction of RHi or derotation on the other hand.

Patients with primary right thoracic curves

Selective analysis of the 28 patients with right thoracic curves showed vertebral derotation to be significantly higher in the apical zone than in the upper instrumented zone ($P < 0.05$). However, there was no significant difference in vertebral derotation between the apical zone and the lower instrumented zone.

The apical RHi decreased by 36% ($P < 0.001$) and the cumulative RHi for the apical region decreased by 32%

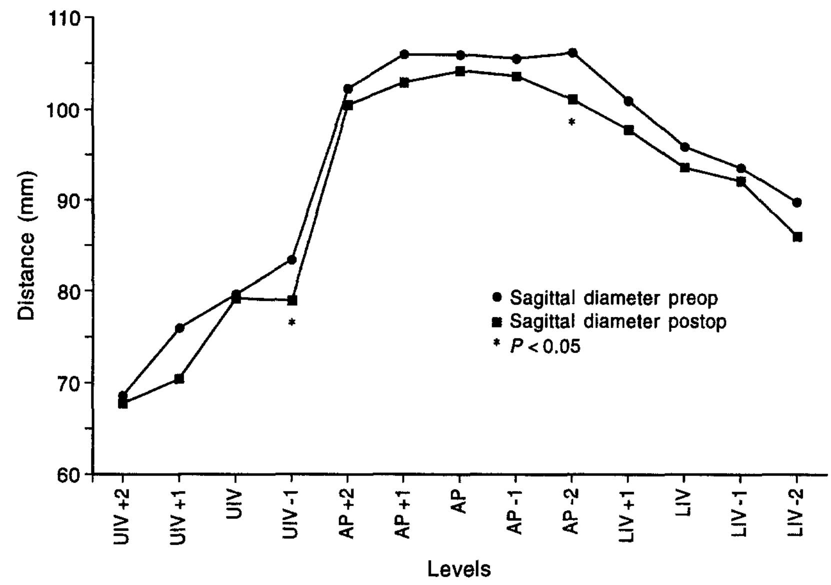

Fig. 6 Mean preoperative and postoperative sagittal diameters in all patients at all levels of the spine. No increase in sagittal diameter was observed at any level

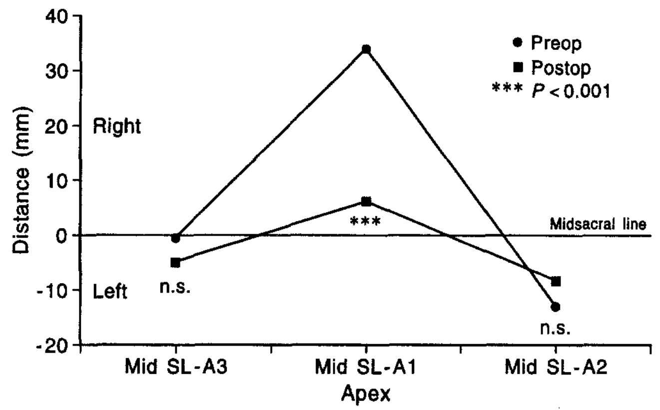

Fig. 7 Mean properative and postoperative distance between the apex vertebra and the midsacral line *(Mid SL)* in the major *(A1)*, the upper *(A3)* and the lower *(A2)* secondary curves in all patients

($P < 0.001$). The RHi calculated for the two levels above and below the instrumentation decreased by 9% and 17%, respectively (n.s.).

The sagittal diameter was reduced in the lower instrumented zone and the transverse diameter was reduced at the apex level. No other significant changes in diameter were observed.

Similarly, the translation of the apex in the coronal plane improved significantly as measured both on radiographs and CT scans. Translation in the secondary curves at the apical level was significantly improved as measured by CT, but not by radiography.

Discussion

The present study showed that CDI results in a three-dimensional improvement in the spinal deformity with a major improvement in the coronal plane and a minor improvement in the horizontal and sagittal planes at all levels studied. Although the effect of the derotational manoeuvre on spine rotation is of obvious technical interest, its biological significance is, in view of the relatively small and also temporary effect, limited [24]. Furthermore, the major concern for the patient with idiopathic scoliosis is the rib hump, the correction of which did not correlate with vertebral derotation at any level. The effect on the thoracic cage was also moderate. Although the rib hump improved, the sagittal and transverse diameters remained largely unaltered at all levels.

Sagittal diameter was also unaltered in the hypokyphotic patients, in whom a significantly improved thoracic kyphosis was observed. In patients with small preoperative diameters, the sagittal diameter was not increased at any level. This may be explained by the stiffness of the thoracic cage [10], which prevents immediate increase in the sagittal diameter. In a previous study we observed an increased sagittal diameter at the apex at midterm follow-up, possibly reflecting remodelling or growth of the thoracic cage [24].

In contrast to the present findings, Shufflebarger et al. showed an increased postoperative chest AP diameter and a significantly improved pulmonary function [20]. Although the importance of the sagittal diameter and thoracic kyphosis for pulmonary function is unclear, a small diameter may negatively influence pulmonary function [2, 19]. It has been reported that loss of physiologic thoracic kyphosis may result in reduced pulmonary function [7, 25]. On the other hand, Lenke et al. found no correlation between improved thoracic hypokyphosis and improvement in pulmonary function [18].

Several radiographic techniques have been developed to study rotational deformity in scoliosis. The CT method allows a segmental analysis of each vertebra within as well as outside the curve. The accuracy of the method is known to be reduced when the inclination of the vertebra in both the coronal and sagittal planes is greater than 20° [1]. The inclination in the coronal plane exceeds 20° at the end vertebrae in larger curves, but it is an unusual occurrence in the sagittal plane, since kyphosis in idiopathic scoliosis rarely exceeds 40°. Thus, the accuracy of the method is acceptable, particularly for longitudinal studies of vertebrae at the same level. In a previous study on vertebral rotation in idiopathic scoliosis, we found the intraindividual precision, expressed as the coefficient of variation of the RAsag (rotational angle to the sagittal line) measurement, to be 5% and the interindividual precision 14.5%, i.e., similar to the precision reported by Aaro et al. [3, 23]. The precision of the measurement of rotation can be considered sufficient for group comparison, as in the present study. In view of the much higher intraindividual precision of the RAsag measurement, it is obviously preferable if measurements can be performed by the same observer, which was the case throughout the present investigation. The traditional method of measuring RAsag involves the use of the sagittal line with no control of possible malposition of the patient on the CT table. Therefore, vertebral rotation in this study was determined as the relative rotation to T1. T1 was used as the reference level instead of S1, used in a previous report, because it is less tilted in the sagittal plane. Since tilt influences the measurement of rotation, the use of T1 as a reference instead of S1 improves the accuracy of the measurement [1].

In our study all patients had standard vertebral rotation, i.e, rotation of the vertebral body towards the curve convexity. Armstrong et al. reported a 7% frequency of rotation to the concavity based on radiographs, probably reflecting differences in methodology as well as the much larger curves in the present study [5].

Several authors have reported that CDI results in a postoperative apical derotation varying between 14% and 43% [13, 14, 21, 24]. The present study showed that CDI results in a significant postoperative derotation of the spine and a significant reduction of the rib hump within as well as outside the instrumented levels of the spine. The derotational effect of CDI was more pronounced in the apical zone than in the proximal and distal regions of the instrumented area. The small proportion of patients with postoperatively worsened rotation were evenly distributed between the sexes and the curve types. The possibility that the majority of worsened rotation results were an expression of the limited precision of the measurement cannot be ruled out.

Some authors, however, have been unable to document a derotational effect of CDI [15, 18]. Based on CT, but with a different measurement technique, Krismer et al. found a worsening of vertebral rotation and rib deformity at the apical level, and no significant derotation at any segment within the instrumented area [17]. Also Gray et al. reported no significant derotational effect, but an improved rib hump, in a limited segmental analysis of CDI [15]. This is in direct contrast to our series, in which a significant derotation was documented at all instrumented levels. These contradictory results might be explained by methodological differences. In the present study the reduction of RHi and of the cumulative RHi was statistically significant and of similar magnitude. The measurement of the apex RHi may therefore be sufficient for quantification of the rib hump.

In a previous study, using the standard measurement of RAsag, we found a significant decrease in postoperative apical vertebral rotation and rib hump of the same magnitude as in the present study [24]. At mid-term follow-up, however, no significant improvement over the preoperative status could be demonstrated. Thus, the observed multisegmental improvement observed in the present study probably deteriorates with time. Using segmental ISIS analysis, Wemyss-Holden et al. reported persistent apical vertebral derotation but a recurrence of the rib hump at 2-year follow-up in patients operated on with CDI [22].

The fact that a positive correlation was found between preoperative vertebral rotation and rib hump, but not between CD-induced derotation and rib hump reduction, may suggest that the mechanism of correction of the thoracospinal deformity by CDI does not work by reversing the postulated development of the deformity [4], i.e., an anterolateral displacement including rotation of the vertebrae in the horizontal plane. The lack of correlation indicates that the correction of vertebral rotation and rib hump by CDI are not the result of the same mechanism.

The findings of a significant correlation between preoperative vertebral rotation and RHi at and above the apex level, but not below the apex, may be explained by the fact that the thoracic cage is less rigid below T10. The results imply a biomechanical relationship between vertebral rotation and rib cage asymmetry, although which is primary and which secondary cannot be elucidated.

Wood et al. found in their study of ten King-Moe type II and III curves no consistent derotation of the thoracic apex vertebra relative to the pelvis. On the other hand it was suggested that segmental changes outside the instrumentation may result in axial decompensation due to "en bloc" derotation [26]. Analysis of the present data showed, however, that CDI causes a gradual derotation of the spine, most pronounced at the apex, with no clear tendency towards "en bloc" derotation.

Although the results of the present study show only a limited correction of the chest cage deformity, one can conclude that CDI results in a postoperative three-dimensional improvement of the spine and the chest cage, with no tendency towards worsened deformity at any level within or outside the instrumentation.

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References

1. Aaro S, Dahlborn M (1981) Estimation of vertebral rotation and the spinal and rib cage deformity in scoliosis by computer tomography. Spine 6: 460–467
2. Aaro S, Ohlund C (1984) Scoliosis and pulmonary function. Spine 9: 220–222
3. Aaro S, Dahlborn M, Svensson L (1978) Estimation of vertebral rotation in structural scoliosis by computer tomography. Acta Radiol Diagn 19: 990–992
4. Adams W (1865) Lectures on the pathology and treatment of lateral and other forms of curvature of the spine. Churchill, London
5. Armstrong GWD, Livermore NB, Suzuki N, Armstrong J (1982) Nonstandard vertebral rotation in scoliosis screening patients: its prevalence and relation to the clinical deformity. Spine 7: 50–54
6. Bernhardt M, Bridwell K (1989) Segmental analysis of the sagittal plane alignment of the normal thoracic and lumbar spines and thoracolumbar junction. Spine 14: 717–721
7. Bradford DS, Blatt JM, Rasp F (1983) Surgical management of severe thoracic lordosis: a new technique to restore normal kyphosis. Spine 8: 420–428
8. Bradford DS, Lonstein JE, Moe JH, Ogilvie JW, Winter R (1987) Moe's textbook of scoliosis and other spinal deformities. Saunders, Philadelphia, pp 63–64
9. Bridwell K, Betz R, Capelli AM, Huss G, Harvey C (1990) Sagittal plane analysis in idiopathic scoliosis patients treated with Cotrel-Dubousset instrumentation. Spine 15: 921–926
10. Closkey RF, Schultz A (1993) Rib cage deformities in scoliosis: spine morphology, rib cage stiffness, and tomography imaging. J Orthop Res 11: 730–737
11. Cobb JR (1948) Outline for the study of scoliosis. Am Acad Orthop Surg Lect 5: 261–275
12. Cotrel Y, Dubousset J, Guillaumat M (1988) New universal instrumentation in spinal surgery. Clin Orthop 227: 10–23
13. Cundy PJ, Paterson DC, Hillier TM, Sutherland AD, Stephen JP, Foster B (1990) Cotrel-Dubousset instrumentation and vertebral rotation in adolescent idiopathic scoliosis. J Bone Joint Surg [Br] 72: 670–674
14. Ecker ML, Betz RR, Trent PS, et al (1988) Computer tomography evaluation of Cotrel-Dubousset instrumentation in idiopathic scoliosis. Spine 13: 1141–1144
15. Gray JM, Smith BW, Ashley RK, LaGrone MO, Mall J (1991) Derotational analysis of Cotrel-Dubousset instrumentation in idiopathic scoliosis. Spine 16: S391–S393
16. King HA, Moe JH, Bradford D (1983) The selection of the fusion levels in thoracic idiopathic scoliosis. J Bone Joint Surg [Am] 65: 1302–1314
17. Krismer M, Bauer R, Sterzinger W (1992) Scoliosis correction by Cotrel-Dubousset instrumentation. Spine 17: S263–S269
18. Lenke LG, Bridwell KH, Baldus C, Blanke K (1992) Analysis of pulmonary function and axis rotation in adolescent and young adult idiopathic scoliosis patients treated with Cotrel-Dubousset instrumentation. J Spinal Disord 5: 16–25
19. Ogilvie JW, Schendel M (1988) Calculated thoracic volume as related to parameters of scoliosis correction. Spine 13: 39–42
20. Shufflebarger HL, Gepstein R, Clark R (1987) Recovery of pulmonary function after Cotrel-Dubousset instrumentation. Orthop Trans 11: 498–499
21. Shufflebarger HL, Ellis RD, Clark C (1989) Cotrel-Dubousset instrumentation in adolescent idiopathic scoliosis. Orthop Trans 13: 79–80
22. Wemyss-Holden SA, Burwell RG, Jacobs KJ, et al. (1993) Segmental evaluation and prediction of the effects of Cotrel-Dubousset instrumentation on the back shape and radiological deformity of adolescent idiopathic scoliosis: surgical and aetiological implications. J Bone Joint Surg [Br] 75, [Suppl II]: 175
23. Willers U, Hedlund R (1990) Comparison of two measurements of vertebral rotation in scoliosis, Acta Orthop Scand [Suppl] 237: 51
24. Willers U, Hedlund R, Aaro S (1993) Mid-term effects of Cotrel-Dubousset instrumentation on the configuration of the spine and the thoracic cage in thoracic idiopathic scoliosis. Eur Spine J 2: 99–103
25. Winter RB, Lovell WW, Moe J (1975) Excessive thoracic lordosis and loss of pulmonary function in patients with idiopathic scoliosis. J Bone Joint Surg [Am] 57: 972–977
26. Wood K, Transfeldt EE, Ogilvie JW, Schendel MJ, Bradford D (1991) Rotational changes of the vertebral-pelvic axis following Cotrel-Dubousset instrumentation. Spine 16: S404–S407