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ORIGINAL ARTICLE

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Preoperative and early postoperative three-dimensional changes of the rib cage after posterior instrumentation in adolescent idiopathic scoliosis

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Abstract Rib cage deformity is an important component of scoliosis, but few authors have reported the three-dimensional (3-D) effect of surgical procedures with posterior instrumentation systems on the shape of the rib cage. The objective of this prospective clinical study was to measure the short-term 3-D changes in the shape of the rib cage at the apex of the curve after corrective surgery of adolescent idiopathic scoliosis by a posterior approach using a multi rod, hook and screw system. The 3-D shape of the spine and rib cage was modelled pre- and postoperatively using a 3-D reconstruction technique based on multi-planar radiography in a group of 29 adolescents with idiopathic scoliosis. Geometrical indices describing the scoliotic deformity of the rib cage were computed from these models and were compared pre- and postoperatively using Student's *t*-tests. The frontal spinal curve correction averaged 53% in the frontal plane, while no significant change was noted in the sagittal plane. Significant changes were noted in the shape of the rib cage: rib hump at the apex and at the adjacent lower level were improved (36% and 38%), and small but significant differences were detected in rib frontal orientation in the concavity of the curves at the apex and adjacent lower rib levels. Multi rod, hook and screw instrumentation systems, such as Cotrel-Dubousset instrumentation, are effective in producing significant improvements in the 3-D shape of the rib cage, but these changes are less important than those observed at the spine level.

Keywords Idiopathic scoliosis · Surgery · Three-dimensional instrumentation · Three-dimensional reconstruction · Rib cage

Introduction

Significant spine correction of adolescent idiopathic scoliosis with a three-dimensional (3-D) posterior multi rod, hook and screw instrumentation system and procedure have been reported by many authors [1, 3, 14, 24], supporting the concept that such instrumentation systems correct in the sagittal as well as in the frontal plane.

However, few authors have reported on the 3-D changes of the rib cage after such surgery. Aaro and Dahlborn [1] have documented a significant reduction of rib hump after correction with Harrington distraction instrumentation, although they conclude that the position of the spine relative to the rib cage stays unchanged in its peripheral position. More recently, Wojcik et al. [32] and Korovessis et al. [22], reporting the effects of Zielke operation on the rib cage in the frontal plane, have shown that such an anterior lumbar instrumentation system will elevate the “mobile” ribs on the concave side of the scoliotic curve, while having no effect on the “stiff” apical convex ribs and increasing the droop of the “mobile” lower convex ribs. Willers et al. [31] have published data about the effect of Cotrel-Dubousset instrumentation (CDI), showing a significant decrease (38%) in the apical rib hump index, which is a measurement similar to the rib hump except that it is made in the transverse plane on a computed tomography (CT) scan. To our knowledge, Labelle et al. [24] are the only authors to have reported the effect of the CDI procedure on the rib cage using 3-D indices.

Although the rib cage is partially corrected after posterior instrumentation, many authors [7, 8, 9, 16, 17, 19, 23, 26, 27, 28] have recommended a rib resection procedure (thoracoplasty) be performed on patients with idiopathic scoliosis under certain circumstances. Since the rib prominence is one of the main reasons why adolescents with idiopathic scoliosis seek treatment, many surgeons may consider that the drawbacks of a cosmetic thoracoplasty (additional surgery, blood loss, decrease in breathing capacity, etc.) are outweighed by the socio-psychological benefits to the patient. This suggests that correction of the rib cage with a 3-D instrumentation system such as CDI may not always be satisfactory to the patient. Previous studies [4, 20, 30] have shown that there is only a weak correlation between surface trunk measurements of scoliotic deformities and Cobb angle measurements, and no correlation between radiographic Cobb angle improvement and trunk deformity correction after surgery in idiopathic scoliosis.

The purpose of this study was thus to evaluate and quantify the 3-D changes in the shape of the rib cage after posterior instrumentation and fusion in order to better understand the real effect of the current multi rod, hook and screw instrumentation systems on the rib cage.

Materials and methods

Twenty-nine adolescents (27 female, 2 male), aged 15±1.7 years, participated in the study. They were recruited over a 5-year period at the scoliosis clinic of our hospital, and were scheduled for surgical correction as determined by one of three orthopedic surgeons, each having over 10 years of experience in scoliosis surgery. There were five subjects with a King type I curve, eight with a King type II, six with a King type III, eight with a King type IV, and two with a King type V [21]. For each patient, a 3-D reconstruction of the spine and of the rib cage was obtained less than 10 days (2.4±2.5 days) before the surgery.

A standard 3-D corrective procedure by a posterior approach and bone grafting was performed using the CD system in 24 cases, the Texas Scottish Rite Hospital system in 1 case, the Universal Spine System in 1 case, the CD Horizon system in 1 case and the Colorado system in 2 cases. The correction maneuvers varied slightly depending on the instrumentation used (see Table 1). A correction maneuver predominantly involving rod rotation and distraction was used in most cases. In a few cases, distraction was not applied and/or a translation maneuver was used to bring the screws/hooks to the rod. However, Delorme et al. [15] have shown that the use of a rod rotation or translation correction technique does not affect the level of correction obtained. On average, 12 levels were fused, typically from T4 to L3. The thoracic spine was instrumented in all cases. The correction was maximised, except for King type II curves.

Table 1 Differences in the correction maneuver with different multi rod, hook and screw instrumentation systems. For the majority of the cases, the correction maneuver involved mainly rod rotation, while three cases involved mainly translation

Instrumentation type	No. of patients	Predominant correction maneuver	Distraction
Cotrel-Dubousset	24	Rod rotation	Yes
Texas Scottish Rite Hospital	1	Rod rotation	Yes
Universal Spine System	1	Translation	No
Cotrel-Dubousset Horizon	1	Rod rotation	No
Colorado	2	Translation	No

Each subject was re-evaluated less than 3 months (43±15 days) after surgery.

Three-dimensional reconstructions of the spine and rib cage were obtained from a multi-planar radiographic technique done with each subject in the standing position, which has been detailed in previous publications [2, 6, 10, 25]. These 3-D reconstructions can be visualised in any desired projection on a computer workstation, and the following geometrical indices were computed from them on the spine:

Computerised Cobb angle in the frontal and sagittal planes. This is an equivalent of the Cobb angle, which is computed in any specified vertical projection of the 3-D curve passing through the vertebrae by calculating the angle between the intersection of two lines perpendicular to the curve at its inflexion points. The computerised Cobb angle and the conventional Cobb angle are highly correlated [13, 29]. In the sagittal plane, it becomes an equivalent of measuring the kyphosis and lordosis.

Balance of the patient, measured as the lateral deviation of the center of T1 from a vertical line passing through the center of L5.

The following geometrical indices were computed on the rib cage as described in previous publications [11,12] at three anatomical levels: the apex and its two adjacent levels (lower and upper):

Frontal (α) and sagittal (β) orientations of the rib. These orientations are defined as the angle between the best-fit plane of the rib in the frontal or sagittal planes respectively as shown in Fig. 1.

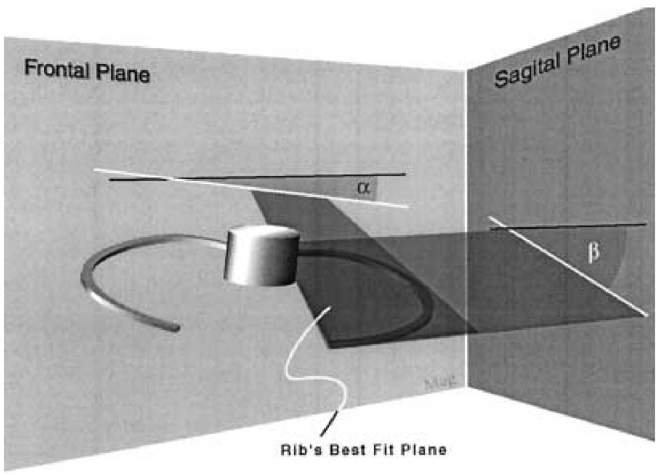

Fig. 1 Frontal (α) and sagittal (β) orientations of the rib

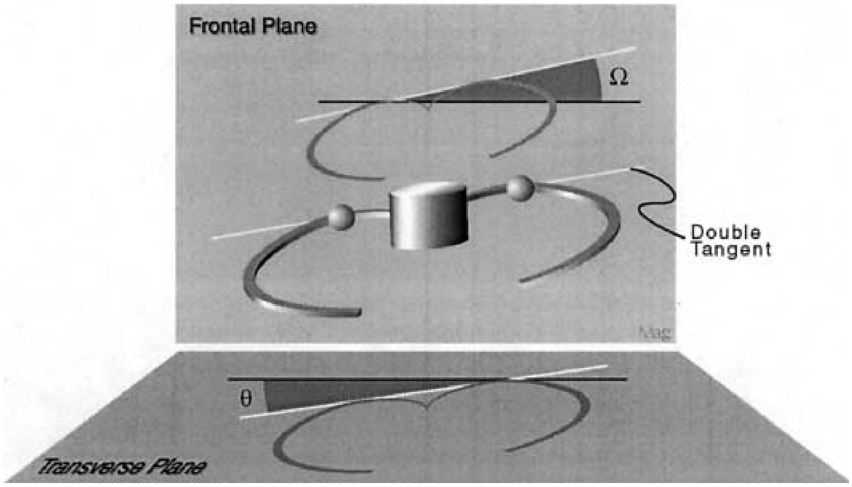

Fig. 2 Rib rotation (rib hump) in the transverse (θ) and in the frontal (Ω) planes

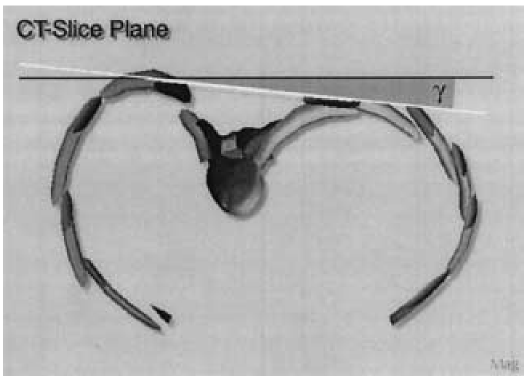

Fig. 3 Rib hump in the computed tomographic (CT) slice (γ)

Rib rotation (rib hump) in the transverse plane (θ). This is measured as the angle, in the transverse plane, of the "double tangent", which is the 3-D line tangential to both the left and right ribs of one anatomical level, as shown in Fig. 2.

The following new geometrical indices were also used:

Rib hump in the frontal plane (Ω). This index is the angle of the double-tangent in the frontal plane, as shown in Fig. 2.

Rib hump in the CT slice (γ). This angle is measured like θ, but on a transverse contour of the rib cage, just as on a CT scan (see Fig. 3). In this case, the double tangent is not necessarily tangent to the same rib level on the left and right sides. The slices are taken on the geometric model at the level of the centroid of the apex and the two adjacent vertebrae.

Every geometric parameter measured in the entire group of reconstructions was compared before and after surgery, using two-sided paired Student *t*-tests. Considering the high number of indices and tests, the level of significance was set at 0.01.

Results

Results for indices measured on the thoracic spine are provided in Table 2.

Curve correction in the frontal plane averaged 53%, from a mean Cobb angle of 58° preoperatively to 27° postoperatively. Thoracic kyphosis in the sagittal plane remained unchanged, although a tendency toward an increase (P=0.076) was noted, from an average of 39° preoperatively to 44° postoperatively. Balance measured in the frontal plane was not significantly changed.

Significant changes in the shape of the rib cage were induced by the procedure. In the transverse plane, rib hump at the apex of the deformity and at the two adjacent levels was significantly improved, by 35% (upper), 37% (apex) and 42% (lower). Similar but slightly smaller changes were also noted for the rib hump in the CT slice, with significant improvement only at the apex of the deformity (31%) and at the lower adjacent level (36%).

Differences were also detected in the frontal plane. On the concave side of the scoliotic curve (left side), ribs at all three levels studied were inclined more downward, with significant decreases in their frontal orientation, especially for the lower rib. On the convex side (right side), only the lower level was inclined less downward, while no changes were noted at the other levels. Those changes decreased the asymmetry between the left and right sides of the rib cage in the frontal plane by 28%. The rib hump in the frontal plane increased significantly at the upper level, indicating that the left extremity of the double tangent is higher than the right one.

No change could be detected in rib sagittal orientation.

Discussion

Significant correction of the rib cage in the transverse plane at the apex of the deformity is induced by 3-D posterior spine instrumentation procedures, but this is only about two-thirds the magnitude of the correction obtained in the spine itself (average rib cage correction of 35% vs 53% for the spine). These findings are comparable to those obtained by other investigators in the transverse plane: Willers et al. [31] reported a correction of the apical rib hump index (an index similar to our rib hump in

Table 2 Means, standard deviations and level of significance of Student's *t*-test for thoracic geometric indices in the group of subjects. All indices are expressed in degrees, except balance which is in millimeters; positive values are counterclockwise on anteroposterior, left lateral and top views (*R* right, *L* left, *Apex+1* level cranially adjacent to the apex, *Apex–1* level caudally adjacent to the apex)

Index	Side/level	Pre-op.	Post-op.	Difference	P
Cobb angle		58±15	27±14	–31	<0.001
Kyphosis		39±18	44±19	5	0.076
Balance (mm)		11± 6	9± 8	–2	0.337
Frontal orientation of the ribs (α)	R/apex+1	32±11	33±11	1	0.860
	R/apex	38±12	37±11	–1	0.420
	R/apex-1	45±16	42±13	–3	0.021
	L/apex+1	–10±13	–14±12	–4	0.035
	L/apex	–15±13	–20±12	–5	0.006
	L/apex-1	–21±13	–28±12	–7	<0.001
Sagittal orientation of the ribs (β)	R/apex+1	40± 9	40± 8	0	0.584
	R/apex	37±10	37±10	0	0.768
	R/apex-1	31±16	30±14	–1	0.283
	L/apex+1	45± 8	47± 8	2	0.324
	L/apex	47± 9	46±10	–1	0.616
	L/apex-1	46±11	44±12	–2	0.268
Rib hump in the transverse plane (θ)	Apex+1	–9±11	–6± 8	3	0.011
	Apex	–10±11	–6± 9	4	0.002
	Apex-1	–11±11	–6± 9	5	<0.001
Rib hump in the frontal plane (Ω)	Apex+1	0± 6	4± 5	4	0.009
	Apex	5± 8	5± 7	0	0.661
	Apex-1	7±10	6± 8	–1	0.417
Rib hump in the CT slice (γ)	Apex+1	–7± 8	–6± 9	1	0.080
	Apex	–10±10	–7± 9	3	0.004
	Apex-1	–10±11	–7± 9	3	0.001

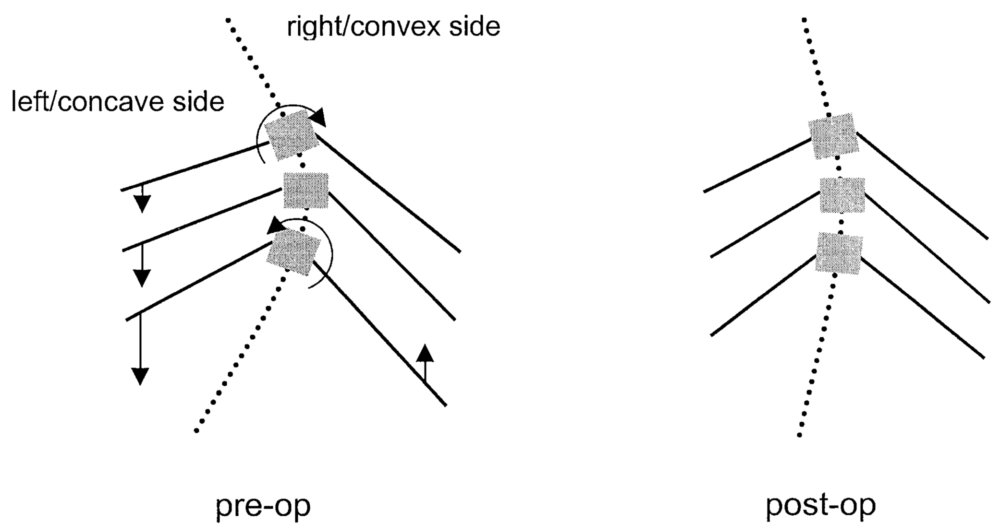

Fig. 4 The effect of posterior instrumentation systems on the rib cage in the frontal plane at the apical level and its two adjacent levels. The lower adjacent rib on the convex side is lifted, while the ribs on the concave side undergo a dropping effect

the CT slice) that measured half the Cobb angle correction (34% vs 67%). These findings confirm that currently available multi rod, hook and screw systems are not as effective for rib hump correction as they are for spine correction. This is probably explained by the fact that instrumentation systems are applied to the spine with maximum correction forces, acting only secondarily on the rib cage.

This is an important finding, since the trunk deformity, and not the spine, is the main problem for which patients seek medical advice, and cosmetic correction of the deformity is an important criterion of success for patients undergoing this procedure. The majority of publications available in the orthopedic literature report radiological frontal Cobb angle curve correction as the main variable to assess correction of this deformity. This study suggests that radiological Cobb angle correction overestimates global correction of the trunk deformity, and should not be the only criterion to assess the value of a surgical procedure in the correction of adolescent idiopathic scoliosis. This finding is also supported by Asher and Manna [4], who reported that surface trunk asymmetry measurements are very different than radiographic measurements, and were unable to find any correlation between trunk correction and Cobb angle correction after surgery in adolescent idiopathic scoliosis. It also suggests that more attention should be given to global correction of a scoliotic deformity, and that rib hump resection (thoracoplasty) should be considered as an additional procedure for subjects with significant rib humps.

The instrumentation also has some effect in the frontal plane on the scoliotic rib cage at the apex and its two adjacent levels, as summarised in Fig. 4. On the concave side, where ribs are more horizontal, ribs undergo a dropping effect which is bigger caudally (7°) than cranially (4°). On the convex side, the most caudal rib is lifted up by almost 4°, while the two other ribs remain stable. Overall, the asymmetry of the rib cage in the frontal plane (difference in frontal orientation between left and right ribs) is reduced by 28%, which is similar but slightly smaller than the correction obtained in the transverse plane. This correction represents slightly more than half the correction of the spine in the frontal plane (28% less rib cage asymmetry vs 53% correction of Cobb angle). This effect may be due to the distraction forces applied by the surgeon on the concave side at the apex resulting in a larger expansion between the ribs. Part of it can also be explained by the change of orientation in the frontal plane of the vertebrae to which those ribs are attached, although it does not explain the drop of the higher ribs on the concave side. Some authors [32, 33] have observed an increase in the rib-vertebra angles – an index similar to the frontal orientation of the ribs, which also includes the orientation of the vertebrae to which it is attached – on the concave side postoperatively, which may explain this phenomenon. Since the average apex level was between T9 and T10 for the present cohort of patients, another explanation is based on the fact that the lower ribs would be more mobile than the higher ribs, and would thus more easily follow the counterclockwise movement of the vertebrae to which they are attached. The higher ribs would undergo antagonist effects, being pulled down by the intercostal tissues and the lower ribs and pulled up by the clockwise rotation of the vertebrae above the apex. The relative stiffness of the costovertebral joints versus the soft tissue connections between the ribs could explain this drop of the higher ribs on the concave side.

These results in the frontal plane are the exact opposite of those reported by Korovessis et al. [22] and by Wojcik et al. [32] on the effect of an anterior instrumentation system. They have shown that after a VDS-Zielke operation, the "mobile" concave ribs are elevated, while the droop of the lower (T11, T12) convex ribs is increased. This suggests that anterior instrumentation systems applied on the lumbar or thoracolumbar spine only may have a different effect on the rib cage than posterior instrumentation systems installed on the thoracic and lumbar spine. In the case of the VDS-Zielke operation, the rib cage only compensates along with the thoracic spine for the correction of the lumbar curve. However, our results are in accordance with those reported by Wojcik et al. [33] on the effect of posterior instrumentation systems (Harrington-Luque and CD) on the rib cage.

The results presented in this study only pertained to the apex and its two adjacent levels. A more global look at the behavior of the ribs attached to all the vertebrae of the scoliotic curve, from the cranial neutral vertebra to the caudal neutral one, would probably allow a more definitive explanation of the behavior of the ribs in the frontal plane. Also, the use of a biomechanical model of the spine and rib cage, such as the one developed by our team for the simulation of brace treatment [5,18], could help in understanding the mechanisms of transmission of the correction from the spine to the rib cage.

Conclusions

Three-dimensional multi rod, hook and screws instrumentation systems, such as Cotrel-Dubousset instrumentation, are effective in producing a significant but smaller improvement in the rib cage compared to frontal curve correction, but changes are minimal in rib orientation in the frontal plane of the concavity. These results emphasise the importance of reporting results of surgery in adolescent idiopathic scoliosis with trunk measurements and not only radiological Cobb angle measurements. They also support the use of rib hump resection as an additional procedure for subjects with significant preoperative rib deformities.

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