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ORIGINAL ARTICLE

Changes of concave and convex rib–vertebral angle, angle difference and angle ratio in patients with right thoracic adolescent idiopathic scoliosis

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Abstract The aim of this study is to describe the radiological changes in rib–vertebral angles (RVAs), rib–vertebral angle differences (RVADs), and rib–vertebral angle ratios (RVARas) in patients with untreated right thoracic adolescent idiopathic scoliosis and to compare with the normal subjects. The concave and convex RVA from T1 to T12, the RVADs and the RVARas were measured on AP digital radiographs of 44 female patients with right convex idiopathic scoliosis and 14 normal females. Patients were divided into three groups: normal subjects (group 1), scoliotic patients with Cobb's angle equal or <30° (group 2) and scoliotic patients with Cobb's angle over 30° (group 3). Overall values (mean ± SD) of the RVAs on the concave side were 90.5° ± 17° in group 1, 90.3° ± 15.8° in group 2 and 88.8° ± 15.4° in group 3. On the convex side, values were 90.0° ± 17.3° in group 1, 86.3° ± 13.7° in group 2 and 80.7° ± 14.4° in group 3. Overall values (mean ± SD) of the RVADs at all levels were 0.5° ± 0.7° in group 1, 4.0° ± 4.8° in group 2 and 8.0° ± 4.0° in group 3. The RVARa values (mean ± SD) at all levels was 1.008° ± 0.012° in group 1, 1.041° ± 0.061° in group 2 and 1.102° ± 0.151° in group 3. RVAD and RVARa values in the scoliotic segment were greater in patients with untreated scoliosis over 30° than in patients with an untreated deformity of <30° or normal subjects. A significant effect between groups was observed for the RVA, RVAD and RVARa variables. Measurement of RVA, RVAD and RVARa should not only be performed at and around the apex of a thoracic spinal deformity, but also extended to the whole thoracic spine.

Keywords Rib–vertebral angle · Rib–vertebral angle difference · Rib–vertebral angle ratio · Adolescent idiopathic scoliosis

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Introduction

The thoracic spine is connected to the rib cage by the costovertebral joints and the relationship between these components can be affected by spinal deformities. The costovertebral joints and the rib cage are thought to play an important mechanical role in providing stability to the thoracic spine, but clinical and experimental data concerning the relationship between rib cage and thoracic spine remains to be non conclusive [1–3].

Introduced by Mehta in 1972, the rib–vertebral angle (RVA) was originally described to differentiate between resolving and progressive infantile scoliosis and it has become a topic of interest for many researchers [4–8]. Subsequently, it has been used in analyses of the effects of various surgical procedures on the rib cage in patients with idiopathic scoliosis and in studies of the shape of the thorax during growth [9–11]. The RVA measurement has been shown to be a valid and reproducible method [12] and its asymmetries are related to age, gender and laterality patterns of the curvature [9]. However, studies of RVA and rib–vertebral angle difference (RVAD) in patients with adolescent idiopathic scoliosis are scarce. Despite later reports of the prognostic importance of RVAD for this latter patients' population, as well as for neuromuscular spinal deformities [13], there are no data regarding the assessment of the ratio between concave and convex RVA (RVARa) in both adolescent scoliotic patients and normal counterparts. The present investigation was undertaken to describe the radiological changes in RVAs, RVADs and RVARas in patients with untreated right thoracic adolescent idiopathic scoliosis and to compare them with normal subjects.

Materials and methods

A retrospective chart and radiograph review was performed for 44 consecutive adolescent female patients with right thoracic idiopathic scoliosis and 14 normal counterparts. The mean age of the patients was 13.9 ± 1.3 years. All patients were followed at our institution during the period 2006–2009. Data were collected on age, gender, curve patterns and Risser sign. Clinical information and follow-up data were obtained from medical records. Patients eligible for study inclusion included those of female gender with a diagnosis of right thoracic adolescent idiopathic scoliosis. The study was approved by the institutional ethics committee of the University of Geneva Hospitals.

We performed a re-examination of the digital radiographs (Cerner Pro Vision Web 5.0.6, Cerner Corporation; Kansas City, MO, USA) of each patient to assess the changes in RVA, RVAD and RVARa in eligible patients and to compare these with the normal values. Radiographs were all taken in a standing position. Scoliotic patients had AP radiographs of the whole spine, including the pelvis and normal subjects had radiographs taken for reasons other than spinal deformities. Measurements of the spinal curvature were performed in the coronal plane using the Cobb method [14]. Concave and convex RVAs, RVADs and RVARas of all scoliotic patients were measured and compared with those of normal subjects. Data were collected from T1 to T12.

The RVA and the RVAD were measured on digital radiographs according to the method described by Mehta [5]. A perpendicular line, the so-called "vertebral line", was drawn to the middle of the lower border of all thoracic vertebrae. Another line was drawn from the midpoint of the head of the rib to the midpoint of the neck of the rib, medial to the region where the neck widens into the shaft of the rib. This line was then extended medially to intersect the vertebral line creating the RVA. The vertebral line was always drawn perpendicular to the lower border of each thoracic vertebra to minimise the bias of vertebral body wedging, particularly at and around the apex of a scoliotic curve [4, 7, 9, 15, 16].

The RVAD was expressed as the difference between the values of the RVA on the concave and the convex side of a curve. The RVARa was calculated as the ratio between the concave and convex RVA. The mean concave and convex RVA, RVAD and RVARa were obtained for each thoracic level. The RVA measurement has been shown to be a valid and reproducible method [12] and all measurements were performed by a single examiner to avoid inter-observer errors. Patients were then divided into three groups: normal subjects (group 1), scoliotic patients with a Cobb angle equal or <30° (group 2) and scoliotic patients with a Cobb angle over 30° (group 3).

Statistical analysis

Data were expressed as frequencies and percentages, and mean and standard deviations, when appropriate. Student's *t* test was used to compare groups in terms of age, gender, Risser sign, angles and deformity. One-way analyses of variance (ANOVA) were performed on RVA, RVAD and RVARa variables to determine if there was difference between groups. If the overall effect was significant, Tukey post hoc tests were performed to find which means were significantly different from one another. The statistical significance was set at $p < 0.05$. The statistical power using an alpha error level of 5% was also calculated for all significant variables detected in this study.

Statistical analysis was performed using STATISTICA 8.0 (StatSoft Inc., 8.0, USA).

Results

A retrospective analysis of 58 digital radiographs of 58 female patients was performed. All patients presented to our outpatient clinic between 2006 and 2009; 44 patients had right thoracic adolescent idiopathic scoliosis and 14 were normal adolescent females.

Forty-four radiographs of scoliotic patients were taken during the period under study (22 in group 2 and 22 in group 3) and 14 of non-scoliotic adolescent females for other reasons, such as back pain and trauma.

Groups 1, 2 and 3 were comparable with regard to age (13.6 ± 1.6, 13.8 ± 1.9 and 14.2 ± 1.9 years, respectively), Risser sign (1.9 ± 2.1, 1.9 ± 1.8 and 2.1 ± 1.6, respectively) and gender (all females). Groups 2 and 3 were comparable with regard to location of the deformity and mean level of the apex of the curve (Table 1). The mean Cobb angle was 19.7° ± 5.7° for group 2 and 46.3° ± 10.8° for group 3, respectively. The mean magnitude of the curve of group 3 was significantly higher than that of groups 1 and 2. In group 1, the mean length of the thoracic spine

Table 1 Clinical details of patients

	N	Gender	Mean age ± SD (years)†	Deformity	Apex	Mean Cobb angle ± SD (°)‡	Lenght T1–T12‡ (cm)	Risser Sign†
Group 1	14	F	13.6 ± 1.6	Normal	N/A	N/A	25.6 ± 2.3	1.9 ± 2.1
Group 2	22	F	13.8 ± 1.9	Right thoracic	T8/9	19.7 ± 5.8	24.7 ± 1.9	1.9 ± 1.8
Group 3	22	F	14.2 ± 1.9	Right thoracic	T8/9	46.3 ± 10.8	24.7 ± 1.0	2.1 ± 1.6
Total	58							

Group 1 normal subjects, group 2 patients with scoliosis of 30° or below, group 3 patients with scoliosis over 30° degrees, *N/A* not applicable

† $p > 0.05$

‡ $p < 0.05$

(25.6 ± 2.3 cm) was significantly higher than in groups 2 (24.7 ± 1.8 cm) and 3 (24.7 ± 1.0 cm). Demographic data are shown in Table 1.

Rib–vertebral angle

A significant effect between groups was observed for the RVA variable ($p = 0.004$). The post hoc tests revealed significant differences between groups at T4, T5, T6, T7, T8, T9 and T12 levels (Table 2).

RVA overall values (mean ± SD) on the concave side were 90.5° ± 17° in group 1, 90.3° ± 15.8° in group 2 and 88.8° ± 15.4° in group 3. Overall values (mean ± SD) of the RVAs on the convex side were 90.0° ± 17.3° in group 1, 86.3° ± 13.7° in group 2, and 80.7° ± 14.4° in group 3. Convex and concave RVA mean ± SD from T1 to T12 in all groups are shown in Table 2.

Rib–vertebral angle difference

A significant effect between groups was observed for the RAVD variable ($p = 0.0004$). The post hoc tests revealed significant differences between groups at T5, T6, T7, T8, T9 and T12 levels (Table 3).

Overall values (mean ± SD) of the RVADs at all levels were 0.5° ± 0.7° in group 1, 4.0° ± 4.8° in group 2 and 8.0° ± 4.0° in group 3. RVAD mean and standard deviations from T1 to T12 for all groups are shown in Table 3.

Rib–vertebral angle ratio

A significant effect between groups was observed for the RVARa variable ($p = 0.006$). The post hoc tests revealed significant differences between groups at T4, T5,T6,T7, T8, T9 and T12 levels (Table 3).

RVARa mean values (mean ± SD) at all levels were 1.008° ± 0.012° in group 1, 1.041° ± 0.061° in group 2 and 1.102° ± 0.151° in group 3. RVRa mean and standard deviations from T1 to T12 for all patient groups are shown in Table 3.

Discussion

The thoracic spine is connected to the rib cage by the costovertebral articulations that are composed of the rib head joint and the costotransverse joint. The rib–head joint links the rib head to the vertebral bodies and the costotransverse joint connects the rib tubercle to the transverse process of the vertebra. Alterations of the costovertebral joint damage the connections between the thoracic spine and the rib cage and could affect the biomechanical role of the costovertebral joints and rib cage in stabilizing the thoracic spine, particularly in lateral bending and axial rotation [1, 17]. Thometz et al. [18] demonstrated that distraction with rib resection preserving costovertebral joints on the convexity did not significantly influence rotation of the apical vertebral body in the coronal and transverse planes, thus suggesting that the costovertebral junction plays an important role in stabilizing the spine. In their experimental study, they showed that resection of three convex ribs directly corrects rib prominence, but does not significantly improve derotation. Therefore, the rib–head joints also play a role as stabilizing structures of the human thoracic spine in the sagittal, coronal and transverse planes. Moreover, biomechanical studies have demonstrated that rib torsion presents a range of movement more than three times the range of movement of cranial–caudal flexion and five times that of ventral–dorsal flexion [17, 18].

In our study, we decided to use RVA, RVAD and RVARa as indexes of the modification of the anatomical relationship between thoracic vertebrae and ribs. Burwell et al. [19] hypothesised that there could be a physiological mechanism in the central nervous system that controls the symmetric postnatal changes in the RVAs during growth, and that major RVADs result from muscle imbalance originating from the central nervous system. According to this hypothesis, RVAs could be an expression of the

Table 2 Rib–vertebral angle on concave and convex side, from T1 to T12

	Side	T1	T2	T3†	T4†	T5‡	T6‡	T7‡	T8‡	T9†	T10	T11	T12†
Group 1	Right side	109.5 ± 5.8	110.0 ± 6.3	109.1 ± 4.7	106.6 ± 7.6	104.2 ± 7.6	100.6 ± 9.5	95.2 ± 11.3	84.7 ± 8.1	77.4 ± 7.5	73.0 ± 8.7	63.6 ± 9.9	51.6 ± 5.4
	Left side	109.6 ± 6.0	109.9 ± 6.6	108.5 ± 4.6	105.9 ± 7.7	104.0 ± 7.5	100.6 ± 9.5	95.2 ± 11.6	84.8 ± 8.3	77.5 ± 8.0	73.1 ± 9.0	61.1 ± 8.7	49.2 ± 7.2
Group 2	Concave side	108.3 ± 7.3	110.1 ± 6.8	107.5 ± 9.2	106.9 ± 10.0	104.5 ± 8.7	97.8 ± 8.9	92.7 ± 8.7	86.7 ± 9.3	82.3 ± 9.1	76.3 ± 13.6	63.3 ± 17.6	46.6 ± 15.0
	Convex side	107.7 ± 6.7	108.1 ± 6.7	104.4 ± 7.4	99.8 ± 6.8	93.8 ± 8.6	86.4 ± 10.6	82.3 ± 10.9	79.0 ± 10.4	76.4 ± 10.5	76.4 ± 9.3	68.0 ± 15.2	53.2 ± 11.9
Group 3	Concave side	103.1 ± 12.7	113.4 ± 8.9	103.8 ± 13.0	103.9 ± 11.5	100.9 ± 8.4	96.7 ± 8.1	91.4 ± 9.6	88.9 ± 8.5	82.9 ± 8.7	78.5 ± 8.7	64.8 ± 14.1	36.5 ± 10.7
	Convex side	107.8 ± 8.4	110.2 ± 6.8	97.8 ± 11.8	91.0 ± 14.3	83.4 ± 12.9	75.4 ± 13.9	71.3 ± 14.7	66.3 ± 13.6	66.7 ± 11.2	70.4 ± 12.6	67.4 ± 19.6	61.2 ± 11.3

Values are expressed as mean ± SD. Group 1 normal subjects, group 2 patients with scoliosis of 30° or below, group 3 patients with scoliosis over 30°

† $p < 0.01$

‡ $p < 0.001$

Table 3 Rib–vertebral angle ratio (RVARa) and rib–vertebral angle difference (RVAD) on concave and convex sides from levels T1 to T12

		T1	T2	T3	T4†	T5†≈	T6†∞	T7†∞	T8‡∞	T9†≈	T10	T11	T12‡∞
Group 1	RVARa	0.999 ± 0.004	1.001 ± 0.006	1.005 ± 0.004	1.006 ± 0.007	1.002 ± 0.006	1.000 ± 0.006	1.000 ± 0.007	0.999 ± 0.013	0.998 ± 0.010	0.999 ± 0.013	1.045 ± 0.146	1.059 ± 0.102
	RVAD	0.1 ± 0.5	0.1 ± 0.7	0.6 ± 0.5	0.6 ± 0.7	0.2 ± 0.6	0.0 ± 0.6	0.0 ± 0.6	0.1 ± 1.0	0.2 ± 0.7	0.1 ± 0.9	2.5 ± 7.8	2.4 ± 4.0
Group 2	RVARa	1.005 ± 0.024	1.026 ± 0.056	1.032 ± 0.089	1.073 ± 0.096	1.119 ± 0.103	1.143 ± 0.139	1.136 ± 0.111	1.187 ± 0.221	1.099 ± 0.204	1.030 ± 0.231	0.968 ± 0.319	0.899 ± 0.294
	RVAD	0.6 ± 2.6	2.6 ± 5.6	3.1 ± 9.2	7.1 ± 9.1	10.7 ± 8.7	11.4 ± 9.9	10.4 ± 7.6	7.7 ± 11.7	6.0 ± 13.6	1.0 ± 16.7	4.6 ± 20.9	6.6 ± 14.9
Group 3	RVARa	0.957 ± 0.095	0.982 ± 0.239	1.085 ± 0.187	1.164 ± 0.210	1.239 ± 0.228	1.321 ± 0.248	1.323 ± 0.299	1.399 ± 0.312	1.297 ± 0.339	1.154 ± 0.241	1.061 ± 0.434	0.631 ± 0.206
	RVAD	4.6 ± 10.2	2.3 ± 26.8	6.9 ± 15.6	12.9 ± 16.4	17.5 ± 14.4	21.3 ± 12.9	19.6 ± 14.2	22.8 ± 11.9	16.7 ± 14.8	8.6 ± 13.6	1.7 ± 24.7	24.1 ± 17.2

Values are expressed as mean ± SD. Group 1 normal subjects, group 2 patients with scoliosis 30° or below, group 3 patients with scoliosis over 30°

† RVARa $p < 0.01$

‡ RVARa $p < 0.001$

≈ RVAD $p < 0.01$

∞ RVAD $p < 0.001$

resultant muscle forces which act on each rib. Similarly, Grivas et al. [8] hypothesised that the differences of the RVAs between patients with small curves could be an expression of asymmetric muscle forces acting on the thoracic cage. They also showed that patients with small curves have underdeveloped thoracic cages as compared to non-scoliotic counterparts and that differences were more apparent in children with thoracic curves.

However, our findings showed that significant RVADs variations were present in patients with both mild and severe right thoracic adolescent idiopathic scoliosis. This observation seems to indicate that the concave–convex asymmetry is not only due to muscle imbalance, but also associated with other mechanical factors. In right thoracic curves, although the causes of the RVA asymmetries are still unknown, it can be presumed that they result from axial vertebral rotation, biplanar spinal asymmetry, relative anterior spinal overgrowth dorsal shear forces in the presence of normal vertebral axial rotation, asymmetry of rib linear growth, and central nervous system mechanisms [9, 16, 19].

Our results show that the RVAs, RVADs and RVARa from levels T1 to T12 have similar characteristic patterns in patients with mild and severe right thoracic adolescent idiopathic scoliosis and that they significantly differ from normal subjects. It has been shown that rib–vertebra angle asymmetries are related to age and gender and that their pattern reflects the common age, gender and laterality patterns of idiopathic scoliosis [10]. For this reason, we decided to include patients of the same gender with similar curve patterns. Sevastik et al. [4], Kristmundsdottir et al. [6], Modi et al. [7], Xiong et al. [15], and Burwell et al. [19] showed that RVADs increase linearly with a wider Cobb angle, convex apical RVA is as important as apical RVAD, and RVADs are largest at two and three vertebral levels above the apex where they correlate significantly and positively with the Cobb angle.

Our findings confirm those previously published. However, in addition, we also observed that concave RVA was similar in patients with curves below 25° and in patients with curves above 40°. On the other hand, significant differences were observed for convex RVA with values lower in patients with curves above 40° as compared to patients with curves below 25°, and these were particularly evident between levels T4 and T9. The decrease in convex RVA, observed in patients with more severe deformities, caused an increase in RVADs. RVADs were significantly higher, from T1 to T10, in patients with a deformity above 40° as compared to those with deformity below 20°. In our opinion, this is because the decline of convex RVA could be a secondary change that becomes manifest when the deformity has become more severe (Tables 2, 3).

These findings are further supported by the analysis of RVARa. In a normal female adolescent, the RVARa is approximately 1 and is an expression of perfect symmetry between the right and left hemi-thorax. On the other hand, RVARa is greater or lower than 1 when the spine is not aligned. We chose to calculate the ratio between concave and convex RVA to decrease the interference of individual anatomical differences. The highest RVARa values were found in untreated patients with right thoracic scoliosis above 40° and especially at and around the apex of the deformity. The increased RVARa is an expression of the more significant convex RVA reduction in patients with more severe spinal deformities.

The RVAD and RVARa increased from T1 to T6, remained stable from T7 to T9, and decreased from T10 onwards. The trend was similar for all scoliotic patients, but values were again higher in patients with spinal deformity over 40° (Table 3; Fig. 1). Our data differ from those published by Sevastik et al. [4] probably due to different curve patterns.

This study has two potential limitations; the first limitation of this research is the relatively small number of subjects in each of the three groups. In this regards, we calculate the statistical power for all significant variables detected in this study using an alpha error level of 5%. We found an average power of 96% showing that the number of subjects in each group was enough to detect a difference when one exists. The second limitation is the cross-sectional nature of the study which makes it difficult to draw any conclusion on the long-term evolution of RVA, RVAD or RVARa.

In conclusion, we recommend measurement of RVA, RVAD and RVARa not only at and around the apex of a thoracic spinal deformity, but also to extend measurements to the whole thoracic spine. The results of the present study suggest that RVAD is related to the magnitude of the curve

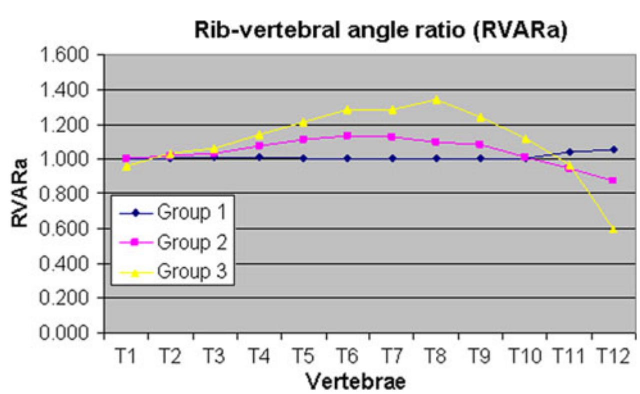

Fig. 1 Pattern of the rib–vertebral angle ratio (RVARa) from levels T1 to T12. Group 1 normal subjects, group 2 patient with scoliosis of 30° or below, group 3 patients with scoliosis over 30°

and that the passive adjustment of the convex ribs to the lateral curve of the spine is a phenomenon that occurs after the decline of concave RVA and when the deformity has progressed.

Conflict of interest None.

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