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Rib-vertebral angle asymmetry in idiopathic, neuromuscular and experimentally induced scoliosis

Received: 17 March 1996
Revised: 11 July 1996
Accepted: 6 August 1996

Abstract The concave and convex rib-vertebral angle (RVA) at levels T2–T12 was measured on AP radiographs of 19 patients with right convex idiopathic thoracic scoliosis and 10 patients with major thoracic right convex neuromuscular scoliosis. The difference between the angles on the concave and the convex sides, the RVAD, was calculated. The RVAs were also measured on radiographs from three animal groups in which spinal curves had been induced experimentally in a variety of ways. Group 1 comprised 16 rabbits that had been subjected to selective electrostimulation of the latissimus dorsi, the erector spinae and the intercostal muscles. Group 2 comprised four dead rabbits whose spines had been subjected to manual bending. Group 3 comprised eight rabbits that had undergone mechanical elongation of one rib. In both the idiopathic and the neuromuscular group, the convex RVA was smaller than the concave RVA between levels T2 and T8, with a maximal difference between T4 to T5. From T9

to T12 the concave RVA was smaller than the convex. The RVA in relation to the scoliotic segment, i.e. the apex level of the curve and the two neighbouring vertebrae above and below this level, showed similar results. With increasing Cobb angle the RVADs increased linearly with the greatest difference at the second vertebra above the apex. In the three experimental groups the pattern of the RVADs between T6 to T12 was basically similar to the findings of the clinical study. From the results of these clinical and experimental studies, it is concluded that the typical pattern of the RVAs on the concave and convex sides seems to be independent of the underlying cause of the spinal curvature. It is likely that the RVADs result from a passive mechanical adaptation of the ribs to the lateral curvature of the spine.

Key words Rib-vertebral angle difference · Idiopathic scoliosis · Neuromuscular scoliosis · Experimental scoliosis

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Introduction

Research on the mechanisms involved during various phases of the development of idiopathic scoliosis (IS) has mainly focused on the three-dimensional changes of the spine. Studies of aspects of the deformity of the thoracic cage, such as the rib hump and rib-vertebra angle (RVA) asymmetry, are scarce.

In 1972 Mehta [18] reported that the difference between the concave and convex RVA, the RVAD, can be used for early differentiation between progressing and resolving infantile IS. This observation was confirmed in later studies [5, 8, 16], and it was further reported that the RVAD is of prognostic importance in juvenile scoliosis as well [17]. Measurements of RVAs have been used in analyses of the effect of various surgical procedures on

the rib cage in patients with IS [26]. RVA values have also been used in studies of the shape of the thorax during growth [11, 27] and it has been suggested that asymmetries between the left and right RVAs result from an imbalance between muscular forces on either side of the spine and that this could be an important factor in the pathogenesis of adolescent IS [3].

There are numerous reports regarding the relation of muscular imbalance to the aetiology, pathogenesis or pathomechanism of scoliosis. In neuromuscular scoliosis it has been proposed that weakness of the trunk muscles on the concave side results in asymmetrical muscle pull on the spine and hence in a curvature [6, 14]. Another study has indicated that there is also weakness of the intercostal muscles on the convex side in thoracic curves [33]. In yet another report it was suggested that weakness of the muscles of the extremities and the trunk is perhaps not related to the development of lateral curvatures. This report suggested that muscular dysfunction could affect the spine differently depending on the age of the individual since, for instance, it is known that scoliosis develops only in children and not in adults with poliomyelitis [15]. It is interesting to note that although paralysis may be responsible for the induction of scoliosis, it is of no importance in determining the side of the convexity in lumbar curves [7].

Idiopathic scoliosis has also been associated with muscular imbalance [9, 10, 21] and it has been suggested that certain generalized neuromuscular disorders can result in IS [30] and that IS could even be considered a primary muscle disease [22]. It has also been suggested that an altered function of cortical central nervous system structures may play an important role in the aetiology of this condition [13]. Although muscle dysfunction is thus considered of importance for the pathogenesis of IS, results of electromyographic studies suggest that the asymmetric electrical activity and muscle fibre distribution in the muscles of the convex side of the scoliotic spine are secondary to the deformity itself [4, 20, 31–33].

The results of many of these studies concerning the importance of muscular imbalance for the development of either idiopathic thoracic scoliosis or neuromuscular scoliosis are in several respects controversial and largely inconclusive, and none of the presented hypotheses enjoy sufficient support from clinical or other observations.

Since the pathogenesis of the RVAD in idiopathic scoliosis has been suggested to be associated with muscular imbalance, it would be interesting to study the pattern of RVADs in idiopathic scoliosis and other, either clinical or experimental, forms of scoliosis with varying muscular involvement. Such a study could elucidate the possible importance of the muscles in the development of differences between the RVAs on the concave and those on the convex side of the scoliotic curve. The present investigation was undertaken in order to study the RVADs in patients with idiopathic and neuromuscular scoliosis and to

compare the findings with those of curvatures experimentally induced in rabbit spines by a variety of techniques: (1) unilateral maximal muscle contraction induced by electric stimulation, (2) manual bending of the spine of dead animals with no muscular tension and (3) unilateral rib elongation.

Materials and methods

Clinical study

The RVA was studied on AP radiographs of 19 patients with right convex thoracic idiopathic scoliosis (IS) and 13 patients with neuromuscular scoliosis. The mean age of the patients with IS was 14.3 ± 1.0 years and for the patients with neuromuscular scoliosis it was 13.6 ± 5.0 years.

The mean Cobb angle in the IS group was $42.9^\circ \pm 9.0^\circ$ and in the neuromuscular scoliosis group, $57.7^\circ \pm 18.1^\circ$. All patients in both groups had right convex thoracic curves. The diagnosis of the patients with neuromuscular scoliosis was neuropathy of the upper motor neurons, according to the classification of the Scoliosis Research Society [19], with cerebral palsy in seven patients, spinocerebellar degeneration in three patients and spinal cord trauma in three patients.

Experimental study

In three animal groups a lateral curvature was induced. In group 1, consisting of 16 growing rabbits, mean body weight 2500 g, unilateral dissection of the latissimus dorsi, the erector spinae and the intercostal muscles was effectuated and a spastic muscle contraction was induced by electrostimulation of each muscle group separately. In group 2 complete absence of muscular tonus was ascertained in four recently killed, full-grown rabbits, having a mean body weight of 3500 g. The spine was bent manually six times to one side in the frontal plane and radiographed each time. In group 3 scoliosis was induced by unilateral medial rib elongation in eight growing rabbits (mean body weight 2500 g).

Groups 1 and 3 comprised animals from two previously presented studies [24, 26].

In all groups the RVAs of the convex and the concave side of the curvatures were measured on radiographs from level T2 to T12 as described by Mehta, and the difference between the two, the RVAD, was then calculated. The mean RVAD for each group was calculated for every level, and these values were used for the analysis. In addition, in the clinical groups, the RVADs of the scoliotic segment, i.e. the level of the apex (V3), the two supradjacent (V1, V2) and two subadjacent (V4, V5) vertebrae were analysed separately and compared with the results of the RVAD measurements of an earlier study of four patient groups with increasing Cobb angles [29].

Student's *t*-test and regression analysis were used for the statistical analysis of the obtained results.

Results

Clinical study

The mean level of the apex of the curves was T9 in both groups.

The mean value of the RVAs of all levels on the convex side was $77.7^\circ \pm 20.6^\circ$ in the IS group and $74.6^\circ \pm 23.7^\circ$ in

the neuromuscular scoliosis group. The mean value of the RVAs on the concave side was $85.8^\circ \pm 27.5^\circ$ in the IS group and $84.3^\circ \pm 30.5^\circ$ in the neuromuscular scoliosis group.

There was no significant difference in the mean values of the RVADs at each level between the idiopathic and neuromuscular scoliosis groups (Table 1) and the pattern of the RVADs along the whole spine from T2 to T12 was

Table 1 The values of the rib-vertebral angle difference (RVAD) (RVA concave – RVA convex) in patients with idiopathic scoliosis (IS) and neuromuscular scoliosis (NS) at each vertebral level (mean $\pm$ SD)

Level	IS (n = 19)	NS (n = 13)
T2	$4.9^\circ \pm 22.4^\circ$	$15.1^\circ \pm 29.6^\circ$
T3	$13.2^\circ \pm 13.5^\circ$	$20.0^\circ \pm 28.1^\circ$
T4	$27.1^\circ \pm 14.5^\circ$	$28.4^\circ \pm 27.9^\circ$
T5	$33.9^\circ \pm 16.6^\circ$	$26.9^\circ \pm 31.2^\circ$
T6	$27.2^\circ \pm 17.6^\circ$	$22.8^\circ \pm 37.6^\circ$
T7	$21.7^\circ \pm 20.6^\circ$	$21.4^\circ \pm 34.3^\circ$
T8	$9.3^\circ \pm 20.0^\circ$	$6.1^\circ \pm 35.5^\circ$
T9	$-0.7^\circ \pm 18.5^\circ$	$-8.7^\circ \pm 30.6^\circ$
T10	$-14.2^\circ \pm 22.1^\circ$	$-12.5^\circ \pm 41.3^\circ$
T11	$-19.1^\circ \pm 19.2^\circ$	$-19.6^\circ \pm 41.2^\circ$
T12	$-15.7^\circ \pm 17.6^\circ$	$-16.6^\circ \pm 29.3^\circ$

Fig. 1 Pattern of the rib-vertebral angle differences (RVADs) from level T2 to T12 in idiopathic and neuromuscular scoliosis (mean $\pm$ SD)

Table 2 Mean RVAD at the apical level (V3) and at two levels above (V1, V2) and two below (V4, V5) in relation to mean Cobb angle in six groups of scoliotic patients, presented in order of increasing Cobb angle

	I ^a (n=23)	II ^a (n=23)	III ^a (n=42)	IV ^a (n=44)	V ^b (n=19)	VI ^c (n=13)
Mean Cobb angle	2.1°	5.7°	11.1°	22.9°	42.9°	57.7°
Range	0°–3°	4°–7°	8°–15°	16°–30°	25°–60°	18°–81°
Mean RVAD						
V1	-1.7°	2.3°	9.8°	15.2°	25.9°	31.9°
V2	-0.2°	-0.4°	5.6°	8.1°	16.4°	14.6°
V3	0.8°	-1.5°	3.6°	1.5°	6.6°	4.8°
V4	0.1°	-3.2°	-1.7°	-3.9°	-6.2°	-7.3°
V5	1.3°	-2.7°	-2.8°	-4.9°	-14.0°	-19.8°

^aResults of groups I, II, III and IV from Xiong et al. [29]

^bResults of the IS group from the present study

^cResults of the NS group from the present study

identical in the two groups. The RVAD increased from T2 to T5, decreased from T6 to T9 and increased from T10 to T12. At T9 the RVAD was minimal, near zero (Fig. 1).

The RVAD measured specifically in the scoliotic segment, at the level of the apex and the neighbouring vertebrae, was similar in the two groups (Table 2).

Experimental studies

The mean Cobb angle was $41.3^\circ \pm 13.3^\circ$ in group 1, $58.0^\circ \pm 26.2^\circ$ in group 2 and $14.3^\circ \pm 4.5^\circ$ in group 3. In groups 1 and 3, where sagittal radiographs and CT scans of the spines were also obtained, it was shown that the experimental procedure induced three-dimensional changes of the spine as seen in IS.

Only a few animals had differences between the RVAs on the concave and convex side above T6, and therefore only the results from T6 to T12 are presented here. The patterns of the RVADs were similar in the three experimental groups and did not differ markedly from those of the clinical groups (Fig. 2).

Discussion

The results of the present study show that the RVADs from level T2 to T12 have the same characteristic pattern

Fig. 2 Mean RVADs from T6 to T12 in scoliotic curves experimentally induced in rabbits by (1) electrostimulation of the latissimus dorsi muscle ($\square$), erector spinae muscle ($\triangle$) and intercostal muscles ($\circ$); (2) manual bending of the spines of dead rabbits ($\blacksquare$); and (3) mechanical rib elongation ($\bullet$)

in both idiopathic and neuromuscular scoliosis, i.e. in two types of curves with presumably different aetiology and with muscular forces exerted on the spine that apparently must be different. Namely, the ribs drop on the convex side above the apex and on the concave side below the apex.

The mean values of the RVADs in the scoliotic segment, defined in relation to the apex of the curve, were greater in the neuromuscular group than in the idiopathic group. This difference can be explained by the fact that the mean Cobb angle was greater in the neuromuscular scoliosis group (57.7°) than in the IS group (42.9°) and the present results show that the RVADs increase linearly with increasing Cobb angle. This becomes more obvious when these values are compared to the results from a previous study [29] where the RVADs were measured in IS patients with curves ranging from 4° to 30° , who were grouped according to the Cobb angle (Table 2, Fig. 3).

The RVADs of the scoliotic spines induced by rib elongation, in the animals of group 3, were smaller than the corresponding values of the rabbits in the two other groups. However, in this group the induced scoliotic deformity was also smaller than in the other two experimental groups (mean Cobb angle 14.3° vs 41.3° in group 1 and 58.0° in group 2), which further supports the relation mentioned above between Cobb angle and RVAD. The present results of the scoliotic segment also show that the RVAD is greater at two levels above the apical vertebra, which accords with the result of the study by Xiong et al. [29] and also with the results of an earlier report of RVA measurements [27].

In this context it must be pointed out that measurements of the RVADs in some earlier studies have concentrated on the level of the apical vertebra [5, 8, 16, 18, 24] where the difference, as seen in the present study, is the least. Earlier conclusions regarding the importance of the RVAD at the apical level could therefore change if this is taken into consideration.

Fig. 3 Mean RVAD at two levels above (V1, V2) and two levels below (V4, V5) the apex level (V3), in relation to the mean Cobb angle in five groups of scoliosis patients (values from Table 2)

The results of the experimental studies showed that the value represented by the concave minus the convex RVA decreased from T6 to T10 and remained unchanged or decreased slightly below this level. Thus, the patterns of the RVADs in the three experimental groups were largely the same as those of the two clinical groups. Differences between the clinical and the experimental results, i.e. differences in the level at which the RVADs were minimal and in the values below this level, which were negative in the clinical series, can probably be ascribed to the anatomical differences between the human thorax and spine and the anatomy of the rabbit, such as the thoracolumbar lordosis and greater rigidity of the human spine.

From the results of extensive studies on the development of the thoracic cage and the RVAs in normal and scoliotic infants, juveniles and adolescent children [11, 12, 27], it was proposed that there is a physiological mechanism in the central nervous system that controls the symmetric postnatal changes of the RVAs during growth, and that major RVADs result from muscle imbalance originating in the central nervous system. This mechanism has been suggested to be of importance for the aetiology of IS [3]. However, a study of the early changes in IS reported a significant wedging of the vertebral bodies and discs in lateral curves of 4° to 7° but noted that significant RVADs appear only in curves of 8° to 15° . These observations were considered to indicate that the concave-convex RVA asymmetry is not necessarily due to muscle imbalance [29]. Together with the results of the clinical and experimental studies of this report, it is suggested that the RVAD in IS is rather the result of other non-muscular mechanical forces, related to the lateral bending of the spine on the one hand, and compression-shortening of the concave side versus decompression-lengthening of the convex side of the thorax, on the other hand, i.e. a passive adjustment of the ribs to the forces exerted on the spine.

An interesting finding in this study was that the transition in the RVAD from negative to positive values occurred at T9 in both clinical groups, i.e. that the RVAD was near zero at this point (Fig. 1). Thus, it seems as if T9 in the clinical material represents the balancing point of the alignment of the normal spine, meaning that this point is exposed to counteracting forces resulting both in the apex of the scoliotic curve, which most often is located at this level [1] and to forces tending to neutralize the RVAD.

In conclusion, the results of the present study suggest that the RVAD develops regardless of the magnitude of underlying muscular imbalance, as a result of a passive adjustment of the ribs to the lateral curvature of the thorax.

Acknowledgements This study was supported by research grants from the Karolinska Institute and the King Oscar and Queen Sophia Golden Wedding Anniversary Foundation, Stockholm.

References

1. Aaro S (1980) Computer tomography in studies of scoliotic deformity. Thesis, Karolinska Institute, Stockholm
2. Aaro S, Dahlborn M, Svensson L (1982) Estimation of vertebral rotation and the spinal rib cage deformity in scoliosis by computer tomography. *Spine* 6:640–647
3. Burwell RG, Cole AA, Cook TA, et al (1992) Pathogenesis of idiopathic scoliosis. The Nottingham Concept. *Acta Orthop Belg* 58:33–58
4. Bylund P (1985) Muscle physiologic studies of the erector spinae in idiopathic scoliosis (in Swedish). Thesis, Karolinska Institute, Stockholm
5. Ceballos T, Ferrer-Torrelles M, Castillo F, Fernandez-Paredes E (1980) Prognosis in infantile idiopathic scoliosis. *J Bone Joint Surg [Am]* 62:863–875
6. Colonna PC, Vom Saal F (1941) A study of paralytic scoliosis based on five hundred cases of poliomyelitis. *J Bone Joint Surg [Am]* 23:335–353
7. Duval-Beaupère G (1971) Pathogenic relationship between scoliosis and growth. In: Zorab PA (ed) *Scoliosis and growth*. Churchill Livingstone, London, pp 58–64
8. Ferreira JH, James JIP (1972) Progressive and resolving infantile idiopathic scoliosis. Differential diagnosis. *J Bone Joint Surg [Br]* 54:648–655
9. Fidler MW, Jowett RL (1976) Muscle imbalance in the aetiology of scoliosis. *J Bone Joint Surg [Br]* 58:200–201
10. Gregori M, Pecak F, Trontelj JV, Dimitrijevic MR (1981) Postural control in scoliosis. A statokinesimetric study in patients with scoliosis due to neuromuscular disorders and in patients with idiopathic scoliosis. *Acta Orthop Scand* 52:59–63
11. Grivas TB, Burwell RG, Purdue M, Webb JK, Moulton A (1991) Segmental pattern of rib vertebra angles in chest radiographs of children: changes related to rib level, age, sex, side and significance for scoliosis. *Clin Anat* 5:272–288
12. Grivas TB, Burwell RG, Purdue M, Webb JK, Moulton A (1992) The rib cage deformity in infantile orthopaedic scoliosis. The funnel shaped upper chest in relation to specific rotation as a prognostic factor. In: Alberti A, Drerup B, Hierholzer E (eds) *Surface topography and spinal deformity*. Gustav Fisher, Stuttgart New York, pp 93–109
13. Herman R, Mixon J, Fisher A, Stuyck J (1985) Idiopathic scoliosis and the central nervous system: a motor control problem. *Spine* 10:1–14
14. Horn CV (1969) Electromyographic investigation of muscle imbalance in patients with paralytic scoliosis. *Electromyography* 4:447–456
15. James JIP (1954) Idiopathic scoliosis: the prognosis, diagnosis and operative indications related to curve patterns and the age at onset. *J Bone Joint Surg [Br]* 36:36–49
16. Kristmundsdottir F, Burwell RG, James IP (1985) The rib-vertebra angles on the convexity and concavity of the spinal curve in infantile idiopathic scoliosis. *Clin Orthop* 201:205–209
17. Mannherz RE, Betz RR, Clancy M, Steel HH (1988) Juvenile idiopathic scoliosis followed to skeletal maturity. *Spine* 13:1087–1090
18. Mehta M (1972) The rib-vertebra angle in the early diagnosis between resolving and progressive scoliosis. *J Bone Joint Surg [Br]* 54:230
19. Moe JH, Winter RB, Bradford DS, Lonstein JE (1978) *Scoliosis and other spinal deformities*. Saunders, Philadelphia London Toronto, pp 7–8
20. Reuber M, Schultz T, McNeill T, Spencer D (1983) Trunk muscle myoelectric activities in idiopathic scoliosis. *Spine* 8:447–456
21. Riddle HFV, Roaf R (1955) Muscle imbalance in the causation of scoliosis. *Lancet* June:1245–1247
22. Sahgal V, Shah A, Flanagan N, et al (1983) Morphologic and morphometric studies of muscle in idiopathic scoliosis. *Acta Orthop Scand* 54:242–251
23. Sevastik B, Willers U, Hedlund R, Sevastik JA, Kristjansson S (1993) Scoliosis induced immediately after mechanical rib elongation in the rabbit. *Spine* 7:923–926
24. Thulbourne T, Gillespie R (1976) The rib hump in idiopathic scoliosis. *J Bone Joint Surg [Br]* 58:64–71
25. Willers U, Sevastik B, Hedlund R, Sevastik JA, Kristjansson S (1995) Three-dimensional effects of electric stimulation of the spine of the rabbit. *Acta Orthop Scand* 66:411–414
26. Wojcik AS, Webb JK, Burwell RG (1990) An analysis of the effect of the Zielke operation on the rib-cage of S-shaped curves in idiopathic scoliosis. *Spine* 15:81–86
27. Wythers DJ, Burwell RG, Webb JK, Wojcik AS (1990) A segmental analysis of rib vertebra angles in thoracic adolescent idiopathic scoliosis: muscle tether and release. Proceedings of the 15th Annual Meeting of the British Scoliosis Society, Southampton, pp 22–24
28. Xiong B (1993) Morphometric studies of the vertebral changes in idiopathic scoliosis. A radiographic and computer tomographic investigation. Thesis, Karolinska Institute, Stockholm
29. Xiong B, Sevastik JA, Hedlund R, Sevastik B (1994) Radiographic changes at the coronal plane in early scoliosis. *Spine* 19:159–164
30. Yarom R, Robin GC (1979) Studies on spinal and peripheral muscles from patients with scoliosis. *Spine* 4:12–21
31. Zetterberg C, Aniansson A, Grimby G (1983) Morphology of the paravertebral muscles in adolescent idiopathic scoliosis. *Spine* 8:457–462
32. Zetterberg C, Björk R, Örtengren R, Andersson GBJ (1984) Electromyography of the paravertebral muscles in idiopathic scoliosis. *Acta Orthop Scand* 55:304–309
33. Zuk T (1962) The role of spinal and abdominal muscles in the pathogenesis of scoliosis. *J Bone Joint Surg [Br]* 44:102–105