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Electrical muscle stimulation on the spine

Three-dimensional effects in rabbits

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We investigated the 3-dimensional effect of electrostimulation of the latissimus dorsi, the erector spinae and the intercostal muscles on spinal configuration in 16 New Zealand white rabbits.

Electrostimulation on the right side of the spine resulted in a left convex, hypokyphotic curve and vertebral body rotation towards the convexity of the curve in all rabbits. The Cobb angle in the coronal plane increased with stimulation of each of the muscles examined. The kyphosis decreased with stimulation of the latissimus dorsi and the erector spinae. The vertebral rotation increased with stimulation of all muscles.

Stimulation of the tested muscles resulted in the simultaneous occurrence of a 3-dimensional spinal deformity with the characteristics of idiopathic scoliosis.

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Although the 3-dimensional nature of scoliosis was noted by Adams as early as in 1865, most experimental studies on scoliosis have been limited to the analysis of the lateral curvature (Adams 1865). The effects of the trunk muscles on the sagittal and horizontal configuration of the spine have previously not been quantified.

Several different types of muscle resections or releases have been reported to induce scoliosis in animals—e.g., muscular imbalance induced by unilateral resection of the erector trunci in rabbits and in monkeys, selective release of various muscle groups in rats and mice, resection of various muscles at different levels on one side of the spine of rats, unilateral or bilateral resection of the sacrospinalis muscles (Arnd 1903, Schwartzman and Miles 1945, Stillwell 1962, Silva 1969). However, unilateral resection of paraspinal muscles in rabbits has been reported to result in kyphosis without scoliosis (Pal 1991). The intercostal muscles have been suspected of playing an etiologic role in scoliosis. Unilateral section of the dorsal portions of the external intercostal muscles in growing rabbits and the detachment of 6 intercostal muscles in monkeys have been found to induce scoliosis (Langenskjöld and Michelsson 1962, Silva 1969).

To examine further, the possible role of muscle imbalance in the pathogenesis of idiopathic scoliosis we have studied the effect of trunk muscles on the rabbit spine in the coronal, sagittal and horizontal planes.

Material and methods

This study was approved by the Ethics Committee for animal experiments at the Karolinska Institute. 16 New Zealand white rabbits with an average weight of 2500 g were used.

The experiments were performed with the animals in the prone position under general anesthesia (diazepam, phenobarbital and atropine). No muscle-relaxing agents were used. The spinal muscles were exposed through a posterior midline incision. The individual muscles were stimulated electrically by using a high voltage galvanic stimulator at 70 V with a frequency of 100 pulses per second. The electrodes were located 2 cm to the right of the spinous processes of T6 and T12 in all animals. 2 spiral needle electrodes for fetal monitoring were adapted to the surface of the muscles. The position of the electrodes was confirmed by fluoroscopy. The muscles were stimulated at the same level of the spine and with the same set-up of the stimulator.

In group A (8 rabbits), AP and lateral radiographs of the spine were taken before and during electric stimulation. The Cobb angle in the coronal and the sagittal planes was measured at the same vertebral levels (Cobb 1948).

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Table 1. Cobb angle measurements in the coronal and sagittal planes in 8 rabbits (group A) before and during electrostimulation of the respective muscles. Values are mean degree, *SD*

	No stimulation		Electric stimulation					
			Latis. dorsi		Erector spinae		Intercostals	
Coronal Cobb angle	0.6	*2.1*	37*	*9.6*	56*	*5.5*	35*	*8.4*
Sagittal Cobb angle	32	*6.5*	22*	*5.1*	24*	*2.5*	27	*6.1*

* $p < 0.05$ (comparing stimulation to no stimulation).

Table 2. Vertebral rotational angle and Cobb angle measurements in 8 rabbits (group B) before and during electrostimulation of the respective muscles. Values are mean degree, *SD*

	No stimulation		Electric stimulation					
			Latis. dorsi		Erector spinae		Intercostals	
Coronal Cobb angle	0.5	*0.9*	34*	*11*	56*	*11*	29*	*10*
Rotational angle	0.9	*1.1*	10*	*3.2*	12*	*2.8*	8.4*	*3.9*

* $p < 0.05$ (comparing stimulation to no stimulation).

In each rabbit, radiographs of the spine were obtained: 1) in the intact rabbit; 2) while stimulating the latissimus dorsi; 3) while stimulating the erector spinae after resection of the latissimus dorsi; and 4) while stimulating the intercostal muscles after resection of the latissimus dorsi and the erector spinae.

The animals were killed at the end of the experiment.

Group B (8 rabbits) was examined by computed tomography (CT). The rotational angle of the vertebral body to the midline—i.e., the angle between a straight line through the posterior central aspect of the spinal canal and the middle of the vertebral body, and a straight line through the posterior central aspect of the spinal canal and the midpoint of the sternum—was measured at the apex level of the curve (Aaro and Dahlborn 1981). The coronal plane Cobb angle was measured on the scout view. The CT scans were obtained before and during electric stimulation of the latissimus dorsi, erector spinae and intercostal muscles, as described above.

Another rabbit (no. 17) was used for EMG studies of the muscle response to electric stimulation. These results showed depolarization of not only the stimulated muscle but also of the more deeply located muscles. Thus, although the electric potentials were lower in the more deeply located than in the superficial muscles, the results cannot be considered to reflect the specific effects of the latissimus dorsi and the erector spinae separately. The effect of the intercostal muscles, however, was more specific, since these muscles were stimulated after resection of the other two spinal muscle groups.

Differences between means observed before and during stimulation were analyzed for significance by the paired 2-tailed Student's t-test. Differences between the separate muscle groups were analyzed by analysis of variance and multiple comparison test (Scheffe). $P < 0.05$ was considered significant.

Results

In all rabbits, electrostimulation of each of the tested muscles on the right side resulted in a powerful muscular contracture and a hypokyphotic, left convex curve with vertebral body rotation towards the convexity of the curve.

The degree of the coronal plane Cobb angles was much the same in groups A and B and increased with stimulation of the latissimus dorsi, erector spinae and intercostal muscles (Tables 1 and 2). The effect of stimulation of the erector spinae on the Cobb angle was more pronounced than that with stimulation of the latissimus dorsi and intercostal muscles ($p < 0.01$). There was no difference between the effects of stimulation of the latissimus dorsi and the intercostals on the Cobb angle (Tables 1 and 2).

The kyphosis decreased with stimulation of the latissimus dorsi and erector spinae, and it did not decrease significantly when the intercostal muscles were stimulated (Table 1). There was no difference between the effects of stimulation of the different muscles on the kyphosis angle. The effect of intercostal electrostimulation was not significant on kyphosis, but it did not differ significantly from erector spinae or latissimus dorsi electrostimulation, as analyzed by analysis of variance.

The vertebral rotation increased with stimulation of the latissimus dorsi ($p < 0.0001$), erector spinae ($p < 0.0001$) and intercostal muscles ($p < 0.01$). There was no difference between the effects on vertebral rotation of stimulation of each tested muscle (Table 2).

Discussion

Stimulation of the intercostal muscles, which have no immediate connection to the skeleton of the spine, resulted in a spinal deformation similar to that seen with stimulation of the genuine dorsal muscles, erector spinae and latissimus dorsi. Although it was not possible to study specifically the latissimus dorsi and the erector spinae separately, our findings suggest a similar effect of stimulation of all 3 muscle groups on the spine in all planes. The stimulation of these muscles resulted in a lateral deviation, extension and rotation of the spine. The observed effect of the latissimus dorsi and erector spinae may have been potentiated by spread of the potentials to more deeply located muscles. This method allowed a more specific study of the intercostal muscles, which showed that the intercostals are mainly responsible for lateral bending and rotation and possibly also result in hypokyphosis of the spine. Moreover, we observed that the spinal deformation occurred instantaneously and simultaneously on the 3 different planes in all animals. Although not quantified, there was no obvious effect of muscle resection on the spinal configuration in the anesthetized rabbits.

Since the trunk muscles do not have identical functions in man and in the rabbit, the validity of the quadrupedal animal model for studying scoliosis can be questioned. The evolution of bipedal gait is accompanied by a different function of the trunk muscles in man from that in animals (MacEwen 1973, Burwell et al. 1992). Besides the functional differences between the species, there are also obvious anatomical differences between man and quadrupeds. The vertebral bodies in rabbits are higher, the cephalic endplates are convex and the caudal flat, whereas the human endplates are biconcave, which may influence the kinematics of the spine in the 2 species. On the other hand, the anatomy of the muscles with regard to location, shape and relative size is similar.

Muscle stimulation in canines and rabbits has been reported to induce thoracic curves with the concavity towards the stimulated side (Monticelli et al. 1975, Olsen et al. 1975). However, in one of the studies, the vertebral body rotation occurred towards the side of the concavity of the curve—i.e., opposite to the side seen in idiopathic scoliosis (Olsen et al. 1975). In none of these experiments has the effect of the experimental intervention been documented and quantified by 3-dimensional analysis of the induced deformity.

Several studies report increased muscle activity on the convex side rather than on the concave side (Riddle and Roaf 1955, Zuk 1962, Redford and Clements 1969, Kaplan et al. 1980, Zetterberg 1982). Myopathic changes in the gluteus maximus and spinal muscles on the concave side of the curve have been observed in patients with idiopathic scoliosis and it has therefore been suggested that the deformity is due to a primary muscular disorder (Sahgal et al. 1983). Higher myoelectric activity, particularly in the deep spinal muscles on the convex side rather than on the concave side, has been thought to result in vertebral rotation, as a first stage in the genesis of scoliosis (Riddle and Roaf 1955). A more likely explanation may be that the increased potentials on the convex side are a secondary phenomenon rather than the cause of the deformity (Zetterberg 1982).

A shorter multifidus muscle on the convex side than on the concave side observed in scoliotic curves has been thought to be caused by increased tonic activity and thus to have etiologic importance in idiopathic scoliosis (Fidler and Jowett 1976). Shortening of the intercostal muscles on the concave side of the curve has been reported in experimental scoliosis in rabbits and it has been suggested that myostatic contracture may be involved in the pathogenesis of scoliosis (Hakkarainen 1981). Roaf (1976) reported, on the basis of an EMG study performed on himself, that arm movements are a main cause of reflex contraction of the intercostal muscles and proposed application of this observation for treatment of scoliotic patients. The results of the current study support the hypothesis that the intercostal muscles are important for maintaining the normal configuration of the spine.

In patients with idiopathic scoliosis, no pathological change in the distribution of fiber types on the convex side has been found. On the concave side, however, fewer type I fibers have been reported, and the asymmetry has been suggested to be part of a primary neuromuscular dysfunction (Bylund 1985). Similar results were found during a study of spinal muscle pathology in experimental scoliosis in rabbits (Barrios et al. 1989).

In conclusion, our results in this experiment indicate that unilateral electric stimulation of the erector spinae, latissimus dorsi or intercostal muscles separately leads to simultaneous spinal deviation in the coronal, sagittal and horizontal planes, with the characteristics of idiopathic scoliosis seen in man.

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References

Aaro S, Dahlborn M. Estimation of vertebral rotation, and the spinal and rib cage deformity in scoliosis by computer tomography. Spine 1981; 6: 460-7.

Adams W. Lectures on the pathology and treatment of lateral and other forms of curvature of the spine. Churchill and Sons, London 1865.

Arnd C. Experimentelle Beiträge zur Lehre der Skoliose. Der Einfluss des Musculus Erector Trunci die Wirbelsaüle des Kaninchens. Arch Orthop Mechan Unf Chir 1903: 1: 145-65.

Barrios C, Tunon M T, Engström W, Canadell J. Paraspinal muscle pathology in experimental scoliosis. Arch Orthop Trauma Surg 1989; 108: 342-5.

Burwell R G, Cole A A, Cook T A, Grivas T B, Kiel A W, Moulton A, Thirwall A S, Upadhyay S S, Webb J K, Wemyss-Holden S A, Whitwell D J, Wojcik A S, Wythers A S. Pathogenesis of idiopathic scoliosis: The Nottingham Concept. Presented at the ESDS meeting, Lyons, France, June 15-17, 1992.

Bylund P. Muscle physiologic studies of the erector spinae in idiopathic scoliosis (In Swedish). Thesis 1985; III:1-III:15, V:1-V:10 .

Cobb J R. Outline for the study of scoliosis. Am Acad Orthop Surg Lect 1948; 5: 261-75.

Fidler M W, Jowett R. Muscle imbalance in the aetiology of scoliosis. J Bone Joint Surg (Br) 1976; 58 (2) 200-1.

Hakkarainen S. Experimental scoliosis: Production of structural scoliosis by immobilization of young rabbits in a scoliotic position. Acta Orthop Scand (Suppl 192) 1981.

Kaplan P E, Sahgal V, Hughes W, Kane W, Flanagan N. Neuropathy in thoracic scoliosis. Acta Orthop Scand 1980; 51: 263-6.

Langenskjöld A, Michelsson J. The pathogenesis of experimental progressive scoliosis. Acta Orthop Scand (Suppl 59) 1962.

MacEwen G. Experimental scoliosis. Clin Orthop 1973; 93: 69-74.

Monticelli G, Ascani E, Salsano V, Salsano A. Experimental scoliosis induced by prolonged minimal electrical stimulation of the paravertebral muscles. Ital J Orthop Traumatol 1975; (1): 39-54.

Olsen G A, Rosen H, Stoll S, Brown G. The use of muscle stimulation for inducing scoliotic curves. Clin Orthop 1975; 113: 198-211.

Pal G P. Mechanism of production of scoliosis. A hypothesis. Spine 1991; 16 (3): 288-92.

Redford J B, Clements E. Use of electromyography as a prognostic aid in the management of idiopathic scoliosis. Arch Phys Med Rehabil 1969; (Aug): 433-8.

Riddle H F V, Roaf R. Muscle imbalance in the causation of scoliosis. Lancet 1955; (June 18): 1245-7.

Roaf R. The intercostal muscles and conditioned reflexes in the control of spinal posture. Proc Roy Soc Med 1976; 69 (March): 177-8, .

Sahgal V, Shah A, Flanagan N, Schaffer M, Kane W, Subramani V, Singh H .Morphologic and morphometric studies of muscle in idiopathic scoliosis. Acta Orthop Scand 1983; 54: 242-51.

Schwartzmann J R, Miles M. Experimental production of scoliosis in rats and mice. J Bone Joint Surg (Am) 1945; 27: 59-69.

Silva J F. Experimental scoliosis on monkeys. SICOT XI Congress, Mexico October 1969 .

Stillwell D L. Structural deformities of vertebrae. Bone adaptation and modeling in experimental scoliosis and kyphosis. J Bone Joint Surg (Am) 1962; 44: 611-34.

Zetterberg C. Paravertebral muscles in adolescent idiopathic scoliosis. An electromyographic and morphologic study. Thesis, 1982.

Zuk T. The role of spinal and abdominal muscles in the pathogenesis of scoliosis. J Bone Joint Surg (Br) 1962; 44 (1): 102-5.