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THE PATHOGENESIS OF EXPERIMENTAL PROGRESSIVE SCOLIOSIS

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In an article published in 1961 we reported that progressive scoliosis can always be provoked in rabbits by resecting the posterior ends of six ribs. Progression up to 170 degrees was observed (Fig.1). Of 15 different operations on nerves, muscles and bones in the vicinity of the spine, rib resection was the only one after which scoliosis occurred in every animal.

The systematic search for different experimental measures provoking scoliosis was continued. After section of the ligaments around the proximal ends of 4—5 ribs, leaving the ligamenta tuberculi costae intact, scoliosis of 50—115 degrees developed in 10 of 21 animals. Section of all ligaments around the costo-vertebral joints (11 animals) gave a similar result.

When we studied the scoliotic vertebrae of pigs which had undergone rib resection, we observed that the deformity of the arch seemed greater than that of the vertebral body (Fig. 2). This has formerly been found to be true also in scoliotic human vertebrae (ROAF). The possible significance of the lamina in the pathogenesis of scoliosis has been stressed by SOMERVILLE.

Working in our laboratory on problems concerning the sequels of lumbar root section, TROUPP found that structural scoliosis often developed in rabbits after hemilaminectomy of lumbar vertebrae. As the 24th type of operation in our series, we performed hemilaminectomy on the right side of 5 thoracic vertebrae in rabbits aged 26—77 days. The hemilaminectomy included removal of the articular processes on the right side. Of these animals 35 survived the operation. A scoliosis of 50—180 degrees appeared in 25 animals. In 11 animals the scoliosis progressed to 80 degrees or more (Fig. 3). As is the case after rib resection, the scoliosis arising after hemilaminectomy is convex to the side of the operation.

Apparently, resection of the posterior ends of ribs, and hemilaminectomy, are two entirely different operations. Even the approach to the resected parts of the skeleton is different in these operations. However, the fact that they may both cause extreme scoliosis led us to search for a common factor in the two operations.

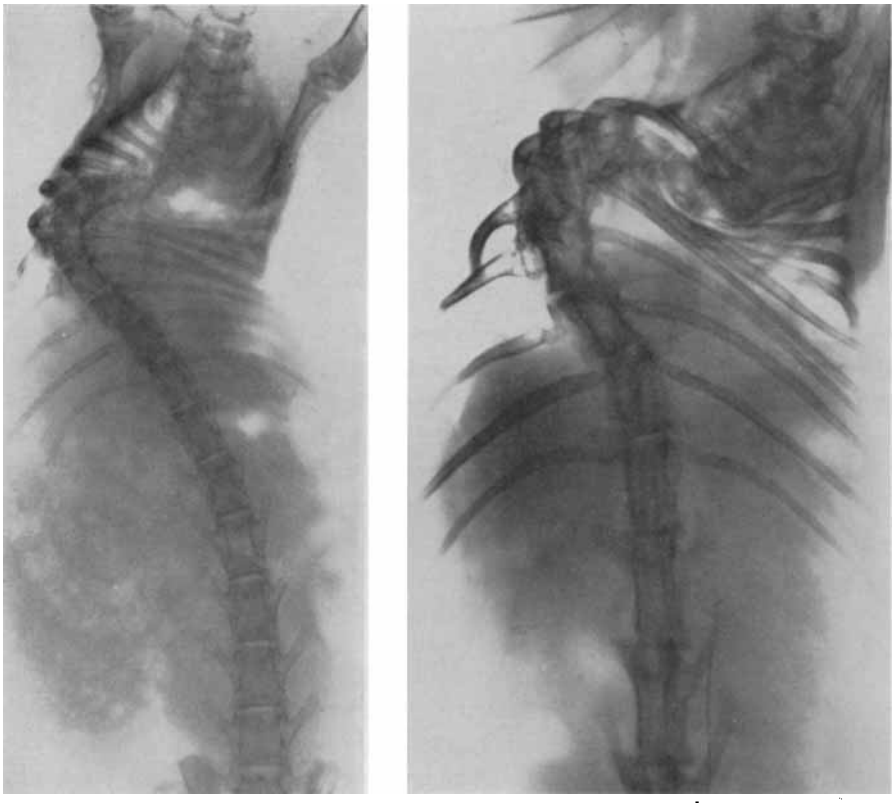

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Fig. 1. Scoliosis in rabbit after excision of the posterior ends of the right sixth to eleventh rib at the age of eight days. a) Age 37 days. b) Age 7½ months. Scoliosis 170 degrees.

A study of the anatomy of the human spine shows that there is a ligament connecting the lamina of each thoracic vertebra with the rib caudal to it (Fig. 4). In the rabbit and the pig there is a corresponding structure. Resection of the posterior end of a rib, or hemilaminectomy, causes loss of function of this ligament. Fig. 5 shows the spine of a rabbit with a scoliosis of 80 degrees which was provoked by section of the posterior costo-transverse ligament at five levels (by FICK called ligamentum colli costae superius ad arcum). As the exposure of this ligament does not produce scoliosis, it appears that the deformity had arisen as a sequel of the section of five tiny strands of connective tissue.

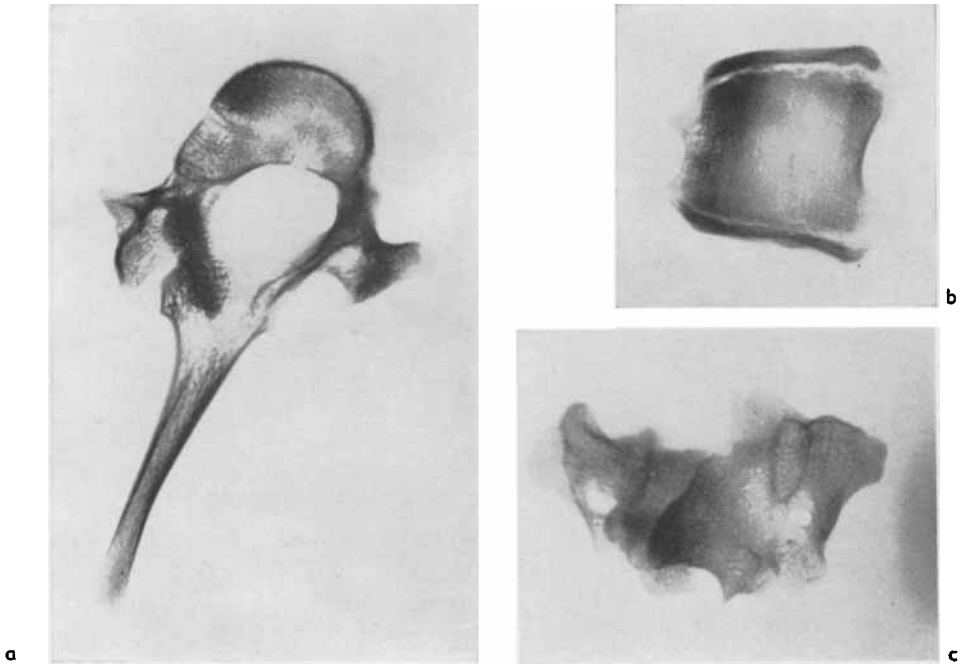

Fig. 2. Pig. Radiographs of scoliotic vertebra. a) axial view. b) Vertebral body. c) vertebral lamina. Radiographs of body and lamina taken at right angles to the plane of maximal distortion.

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Fig. 3. Rabbit. Scoliosis after hemilaminectomy on the right side of the sixth to tenth thoracic vertebrae at the age of 31 days. a) Age 53 days. b) Age 86 days. c) Animal killed at the age of 6½ months. Scoliosis 180 degrees.

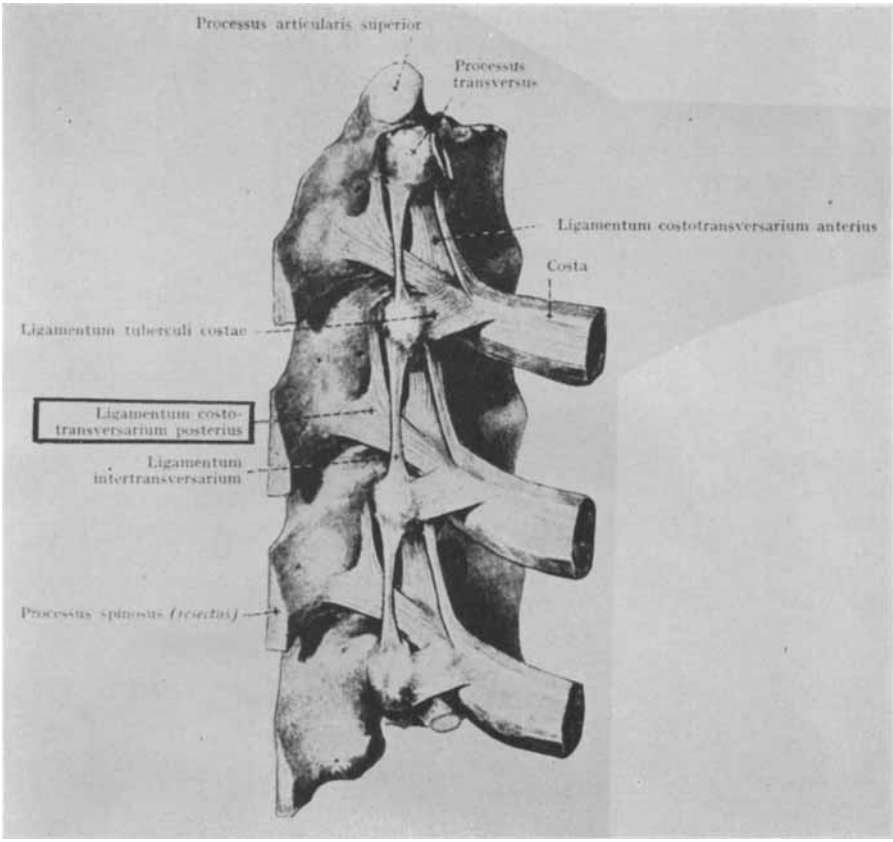


Fig. 4. Ligaments connecting the ribs to the spine. (From Spalteholz).

Severe progressive scoliosis was only seen in a few of 47 rabbits on which section of the posterior and anterior costo-transverse ligaments was done at five levels. Scar formation seemed often to prevent the deforming effect of the operation. There are, however, other facts indicating the importance of the posterior costo-transverse ligament to the stability of the spine.

Functional scoliosis arising immediately after operation on the spine or in its vicinity

In 66 rabbits in which the posterior ends of five ribs were resected, the initial scoliosis was estimated from radiographs taken immediately after the

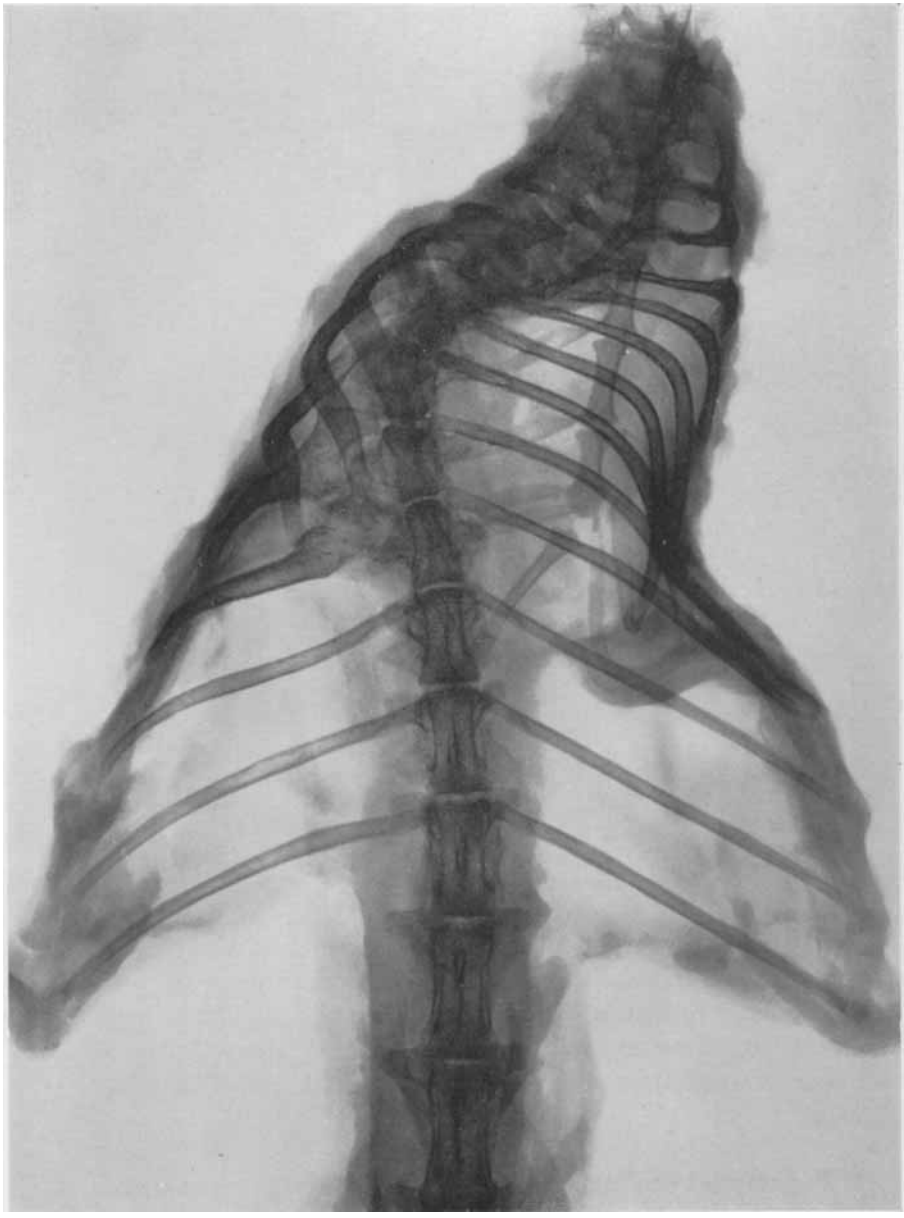


Fig. 5. Rabbit. Posterior costo-transverse ligaments attached to thoracic vertebrae V—IX discised at the age of 33 days. Scoliosis 80 degrees when animal was killed at the age of almost 6 months.

operation. The average scoliosis was 53 degrees (minimum 25 degrees, maximum 85 degrees). In 35 rabbits on which hemilaminectomy was carried out on five thoracic vertebrae, the average initial scoliosis was 39 degrees (minimum 20 degrees, maximum 50 degrees). In 47 animals on which the anterior and posterior costo-transverse ligaments and the intertransverse ligaments were discised at 4—5 levels, the average initial scoliosis was 41 degrees (minimum 5 degrees, maximum 80 degrees).

Even after other types of operations around the ends of the ribs, in connection with which the posterior costo-transverse ligaments were discised, an initial scoliosis of 40—50 degrees was seen.

Unilateral excision of the erector trunci or of all muscles attached to the laminae and spinous processes can provoke an initial scoliosis of 10 degrees.

The initial scoliosis produced by the procedures mentioned above, disappears completely when the rabbit is killed, or subjected to deep general anaesthesia, on the day of the operation. This proves that this initial scoliosis is entirely functional, maintained by the muscle tone. The effect of the muscles on the position of the spine is altered as a result of the operation.

The smallest operation which provoked a high degree of initial scoliosis, was section of the posterior costo-transverse ligament at 4—5 levels. Loss of function of this ligament is also the only common factor which we could find in the other operations producing marked initial scoliosis.

Section of the posterior parts of the intercostal muscles increases the functional deformity arising after section of the costo-transverse ligaments (MICHELSSON).

Progressive scoliosis in the lumbar spine of rabbits

Hemilaminectomy of 4—5 lumbar vertebrae is followed by scoliosis. This operation was performed on 9 animals. Progression to severe deformity was observed in two of them (Fig. 6).

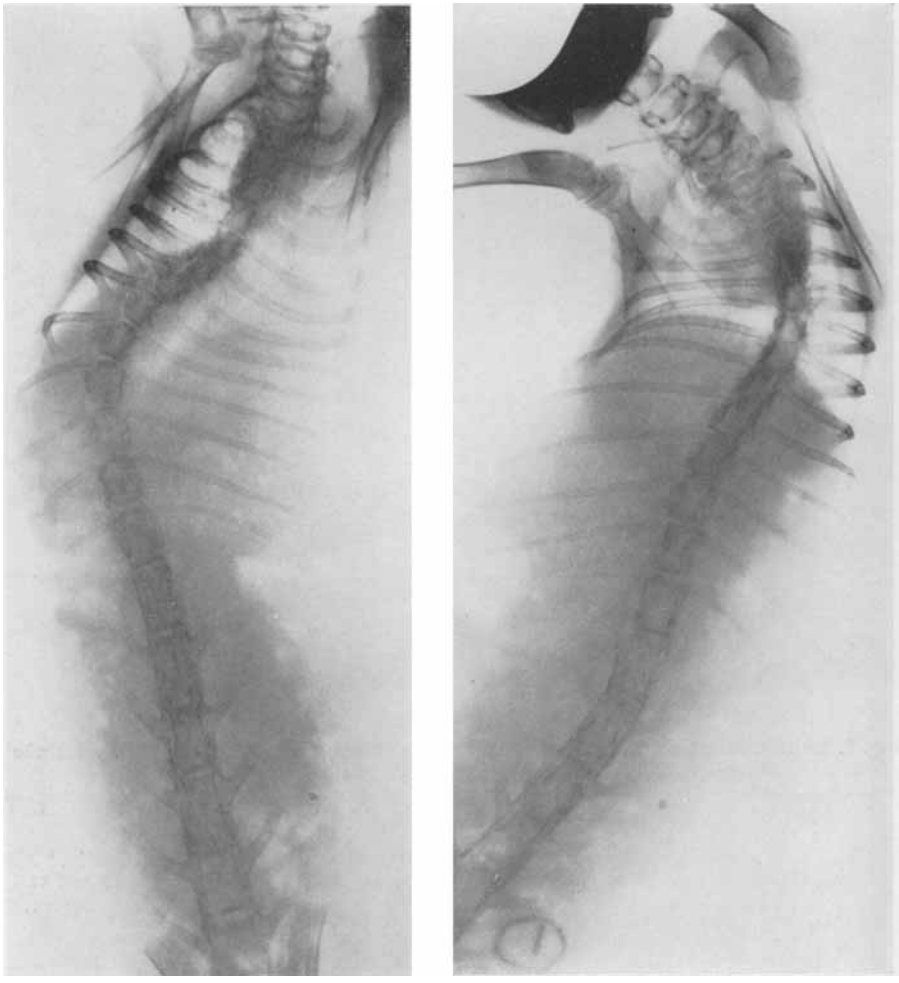
In the lumbar spine, the function of the muscles connecting a lamina to the transverse process caudal to it may roughly correspond to the function of a posterior costo-transverse ligament in the thoracic spine. In 8 rabbits the short muscles between the transverse processes and between these and the laminae were discised at five levels in the lumbar spine. Moderate structural scoliosis occurred in all animals (Fig. 7).

Fig. 6. Rabbit. Hemilaminectomy on the right side of lumbar vertebrae I—IV at the age of 28 days. a) Initial scoliosis immediately after operation. b) Animal killed 3½ months later. Scoliosis 110 degrees.

Fig. 7. Rabbit. Muscles connecting laminae and transverse processes of lumbar vertebrae I—V discised at the age of 30 days. Scoliosis 35 degrees.

Straightening of scoliotic spines of rabbits after secondary operations

In order to neutralize or convert the deforming forces during the progression of experimental scoliosis, several different operations were performed. The most effective of these procedures was discision of the posterior and the anterior costo-transverse ligaments on the concave side. On 11 animals with a scoliosis provoked by hemilaminectomy or by discision of ligaments and intercostal muscles, a secondary operation was carried out. In all animals the



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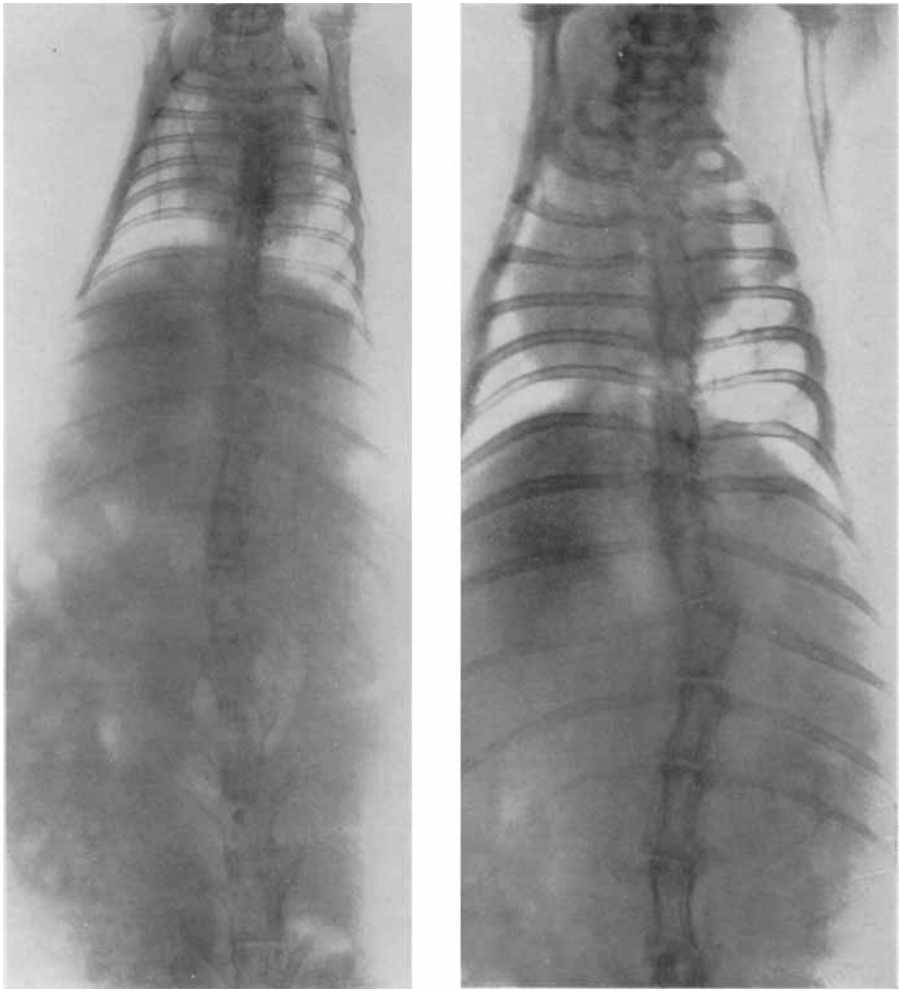
ligaments mentioned above were discised on the concave side, and in some of them a reconstruction with nylon thread of the posterior costo-transverse ligament on the convex side was attempted. In some of the rabbits parts of the intercostal muscles were discised.

In 8 of the 11 animals the spine grew almost straight from a scoliosis of 45—85 degrees.

Fig. 8. Rabbit. Hemilaminectomy of thoracic vertebrae VI—X on the right side at the age of 37 days. a) Age 46 days. Scoliosis 70 degrees in resting position. b) Age 46 days. Fixed scoliosis 25 degrees when trunk was bent to the right. c) Spine almost straight in resting position 12 days after section of anterior and posterior costo-transverse ligaments and parts of the intercostal muscles in the interspaces Th VI—IX on the concave side. Age 58 days. d) Scoliosis converted to other side. Age 5 months.



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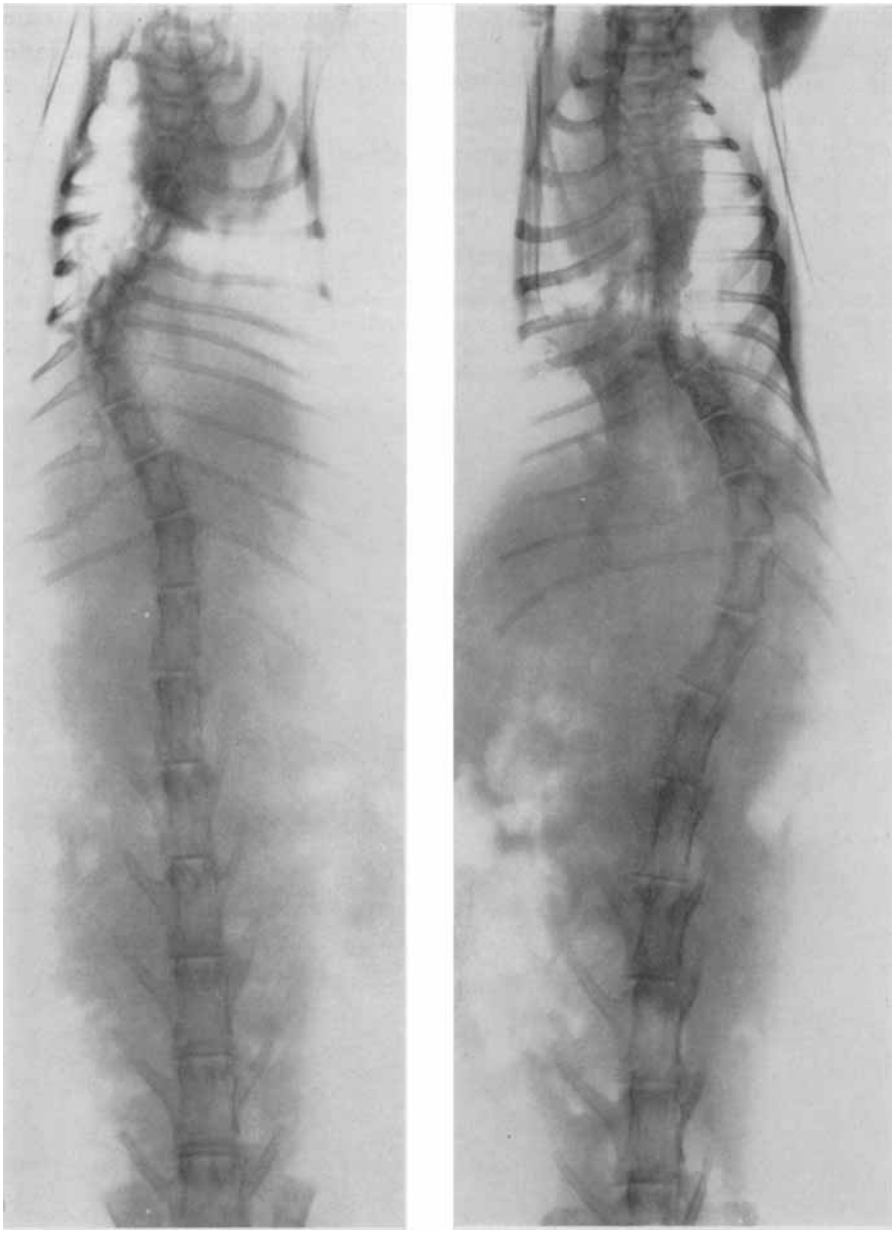


Fig. 9. Rabbit. Excision of the posterior ends of the right sixth to tenth rib at the age of 14 days. a) Age 62 days. Scoliosis 55 degrees. b) Four days after hemilaminectomy of vertebrae Th VI—X on the concave side. Note exaggeration of the caudal secondary curve.

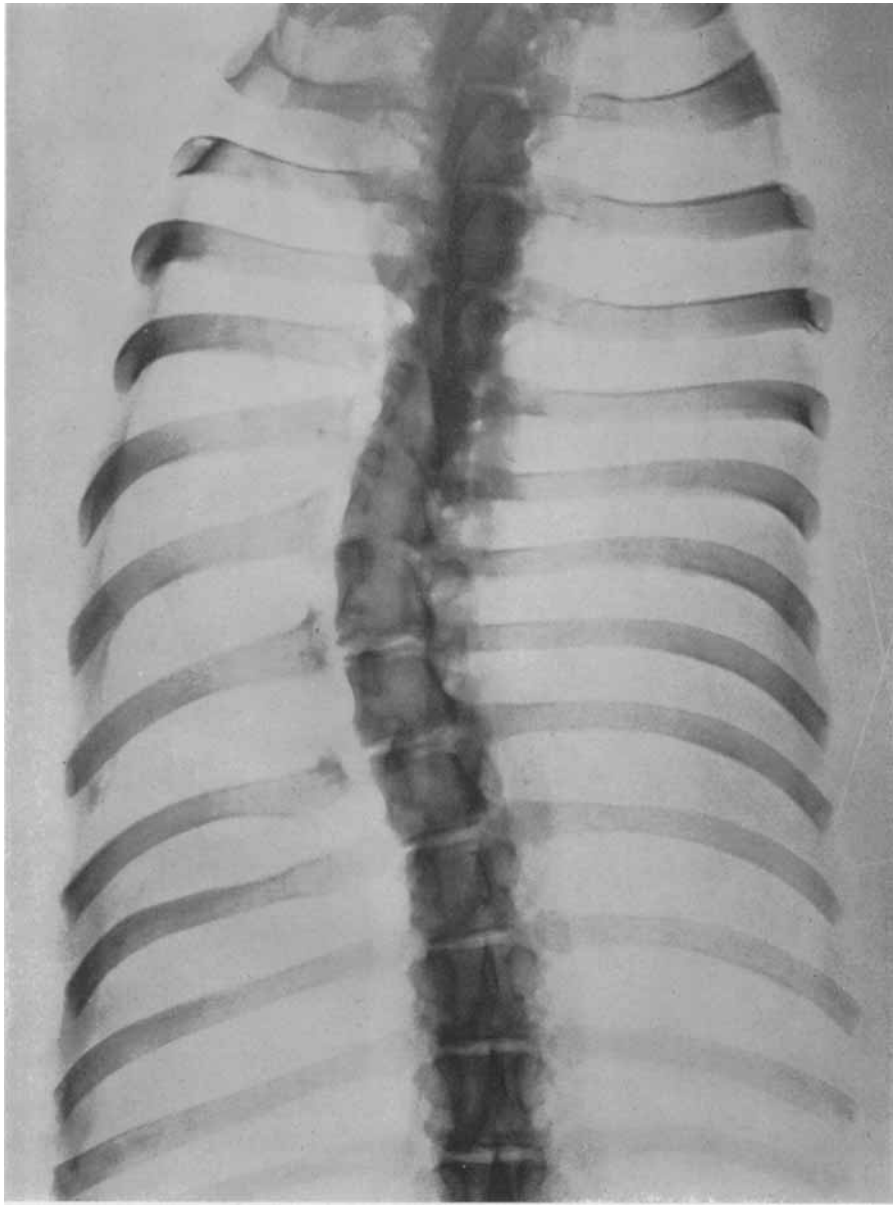


Fig. 10. Pig Excision of the posterior ends of the right sixth to tenth rib at the age of 38 days. Scoliosis 30 degrees four months after operation. (The pig has 28 ribs).

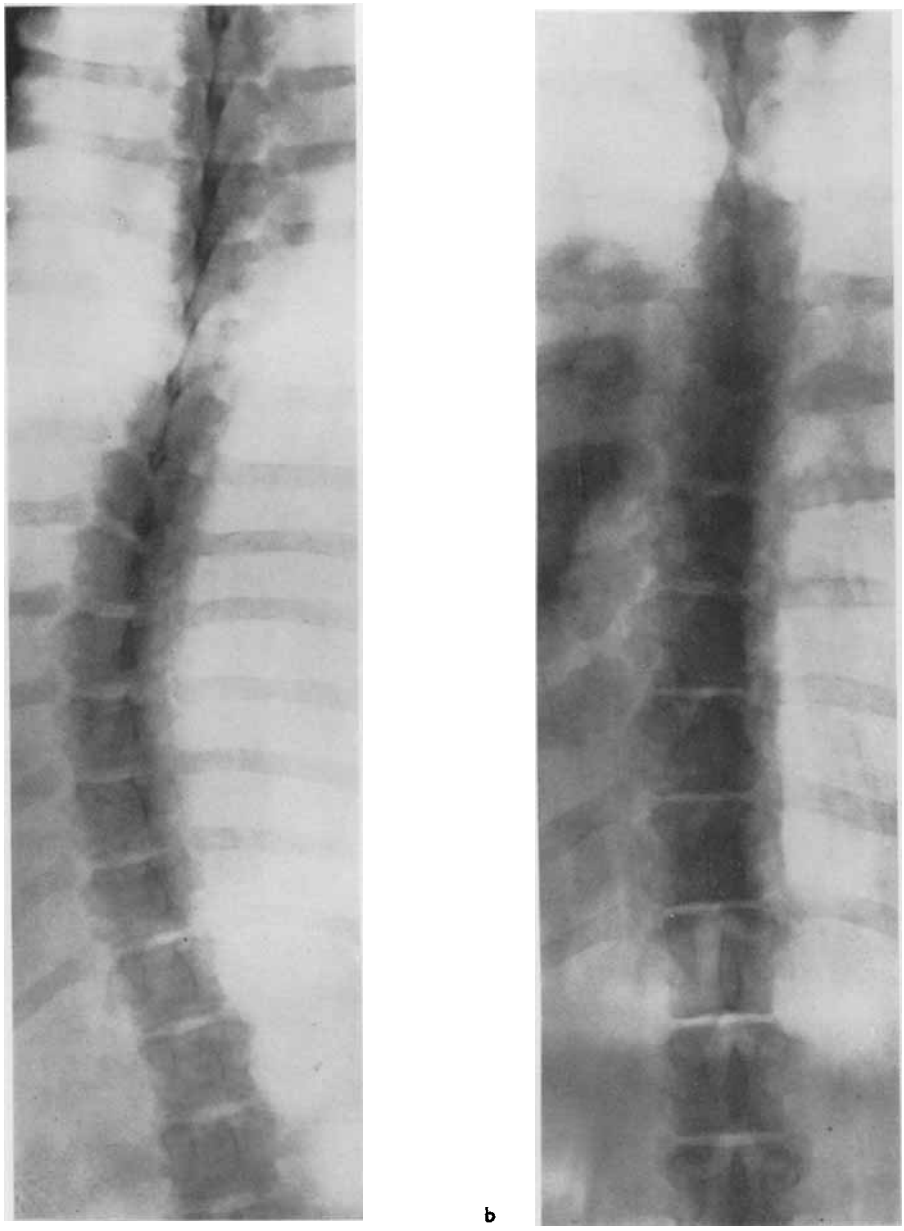


Fig. 11. Pig. The posterior and anterior costo-transverse ligaments were cut at five levels caudal to the seventh thoracic vertebra at the age of nearly two months. a) Ten days after the operation scoliosis 35 degrees. b) Two months after section of these ligaments at four levels on the concave side and reconstruction of the posterior costo-transverse ligaments at the same levels on the convex side. Scoliosis 5 degrees.

Fig. 8 shows an example of the straightening effect of a secondary operation of the concave side. Although some spontaneous straightening has been seen in scoliotic rabbits, there is no doubt that the procedure on the concave side can neutralize the deforming forces.

Some straightening effect was also seen after hemilaminectomy on the concave side of curvatures provoked by rib resection. Fig. 9 demonstrates a phenomenon which sometimes appeared after secondary operations. A hemilaminectomy on the same levels on which the scoliosis-provoking rib resection had been made on the opposite side, caused progression of the caudal secondary curve. This experiment shows clearly the growth conducting power released by both operations, and the importance of a proper localization of any curative operation. In addition, it may indicate a potential danger if untimely use is made of these methods in the treatment of scoliosis in man.

Experimentally provoked scoliosis in pigs

Resection of the posterior ends of five ribs was carried out on 12 pigs (Fig. 10). In 11 of these a scoliosis of 20—75 degrees developed (average 37 degrees).

In 10 pigs the posterior and the anterior costo-transverse ligaments were cut at 5 levels. A scoliosis of 30—45 degrees developed in 9 of these animals. In 4 of the pigs the ligaments mentioned and the intercostal muscles at a distance of some centimeters from the vertebrae were discised on the concave side 3—4 weeks after the first operation. In two of the four animals a reconstruction with nylon thread of the discised posterior costo-transverse ligaments on the convex side was also attempted. After these secondary operations the scoliosis in three of the pigs was corrected to less than 10 degrees (Fig. 11). In the 5 scoliotic animals which had no secondary operation there remained a deformity of at least 24 degrees.

Fig. 12 shows the deformity of the ribs and the rotation of a vertebra in a pig made scoliotic by a soft tissue operation.

Scoliosis exceeding 90 degrees has until now been seen in pigs only after progression following a second operation (Fig. 13).

Fig. 12. Pig. Vertebra and ribs at the apex of a scoliosis (40 degrees) provoked by section of the posterior and anterior costo-transverse ligaments and parts of the intercostal muscles at five levels. Note rotation of vertebra and distortion of the thoracic cage.

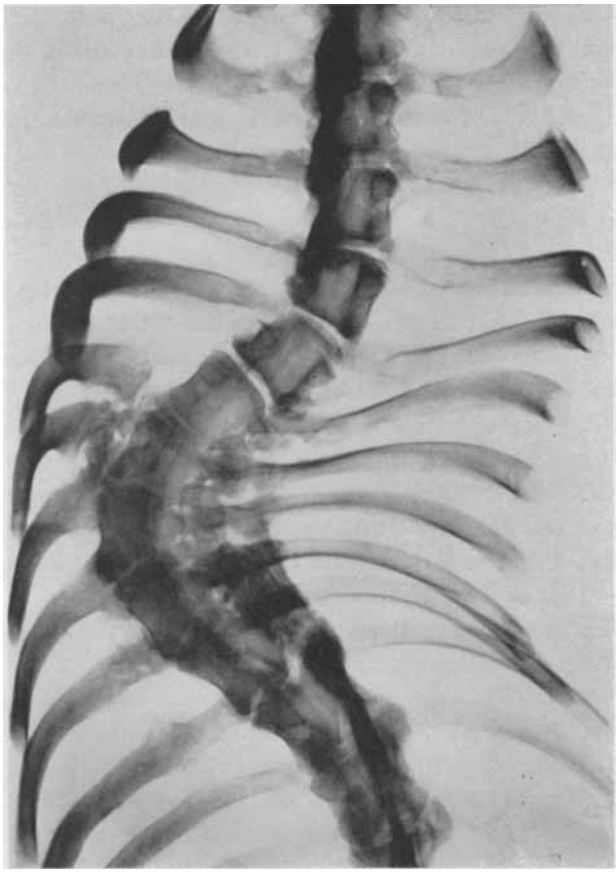


Fig. 13. Pig. Excision of the posterior ends of the seventh to eleventh rib on the right side at the age of one month. Laminectomy of vertebrae Th VI—XI 40 days later when a scoliosis of 40 degrees had developed. At the age of 7 months scoliosis over 100 degrees.

Discussion

The only factor which the scoliosis-provoking operations seem to have in common is the loss of function of the posterior costo-transverse ligament (ligamentum colli costae superius ad arcum). In textbooks on human anatomy it has been pointed out that this ligament transfers the effect of the iliocostalis and the longissimus muscles from the ribs to the vertebrae (BRAUS).

We have arrived at the conclusion that the loss of function of the posterior costo-transverse ligament is the most important factor provoking scoliosis in these experiments. The most effective suppression of this function is the resection of a part of the skeleton to which the ligament is attached (resection of the end of the rib, or hemilaminectomy).

The deforming effect of unilateral division of the posterior costo-transverse ligament and the straightening effect of its section on the concave side of a provoked scoliosis also seem to justify the following conclusions as to the pathogenesis of the spinal deformities described above.

The posterior costo-transverse ligament, in transmitting the effect of normal muscle tone to the spine, is of decisive importance to its equilibrium and symmetrical growth.

A unilateral protracted insufficiency of the function of the posterior costo-transverse ligament at several levels of the spine of a growing rabbit or pig, causes progressive scoliosis of the same type that is seen in man.

In the experiments described above, the deforming forces have been transmitted to the vertebral body by the arch.

Loss of function of the posterior costo-transverse ligament on one side is followed by shortening of the corresponding ligament on the other side. This contracture is soon followed by contracture of other structures.

Scar formation in the region of the posterior costo-transverse ligament or shrinkage of this structure may affect the growth of the vertebra and cause scoliosis. Cicatrization may reestablish the function of a discised ligament.

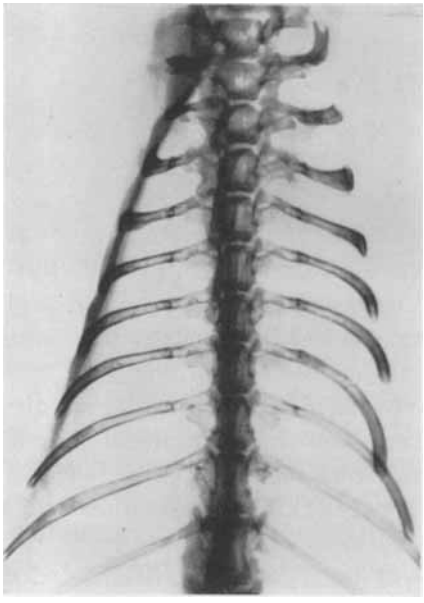
It is obvious from the anatomy of the posterior costo-transverse ligament that a shrinkage of it leads to a deformity composed of lateral flexion and rotation of the spine.

Some facts pointing to connections between the experimental results and scoliosis in man may be stressed.

Fig. 14 shows a scoliosis appearing as a sequel of poliomyelitis in a child. On the convex side there is typical drooping of the ribs. Fig. 15a shows a radiograph of the spine and parts of the ribs of a normal rabbit. All muscles had been excised from the left half of the specimen, which had been

Fig. 14. Human. Scoliosis after poliomyelitis. Note drooping of ribs on the convex side. →

Fig. 15. Rabbit. a) Thoracic spine and posterior halves of the ribs of a normal animal. All muscles have been cut away from the left half of the specimen. Radiograph taken with specimen in an erect position. b) Same specimen as a). On the left side the posterior costo-transverse ligaments have been discised. The ribs have developed a droop. Compare with fig. 14. ↓ ↘



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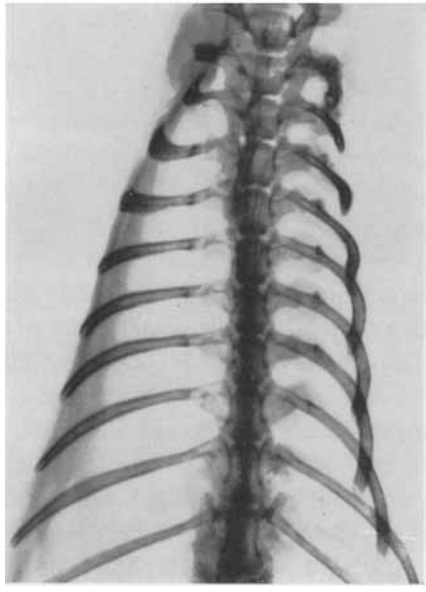

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radiographed in an erect position. Fig. 15b shows the same specimen after discision of the posterior costo-transverse ligaments on the left side. The ribs are drooping. Insufficiency of the function of this ligament may perhaps be a factor through which paralysis affects the equilibrium and growth of the spine.

Fig. 16a shows a radiograph of the spine of a girl aged 10 years. In early childhood an abscess had caused a scar in the tissues on the left side of the spine. The scar extended to the vertebral laminae. The picture shows the spine one week *after* excision of the scar. There is scoliosis of 50 degrees and considerable structural changes. Fig. 16b shows the same spine one year later. There was no other treatment than the operation. The spine had straightened almost 40 degrees. In connection with the excision of the scar, performed by A. LANGENSKIÖLD, the medial parts of several posterior costo-transverse ligaments had probably been removed. At the time of the operation we did not yet know the importance of the ligaments in the pathogenesis of experimental scoliosis. This case proves that a moderate structural scoliosis in a child may correct itself by growth after an adequate operation in which the deforming factors are removed or transferred to the other side.

The facts reported in this article constitute the essential results of experiments on about 650 rabbits and 50 pigs.

Many other observations made in the experiments will be reported in a thesis by J.-E. MICHELSSON.

Summary

Progressive scoliosis can always be produced in rabbits by removing the posterior ends of 5—6 ribs (Fig.1). By hemilaminectomy of five vertebrae in the thoracic spine the same condition arises in more than 2/3 of the experiments (Fig. 3). The only factor common to these two operations seems to be the loss of function of the posterior costo-transverse ligament (ligamentum colli costae superius ad arcum). Progressive scoliosis can be provoked in rabbits by unilateral section of this ligament at five levels in the spine. The primary curve is convex to the side of the operation.

Moderate structural scoliosis is always seen in pigs after unilateral discision of the anterior and the posterior costo-transverse ligaments at 5 levels in the spine (Fig. 11). Scoliotic spines in rabbits and pigs can be made to grow straight by section on the concave side of the ligaments mentioned and parts of the intercostal muscles (Figs. 8 and 11).

A protracted unilateral insufficiency of the function of the posterior

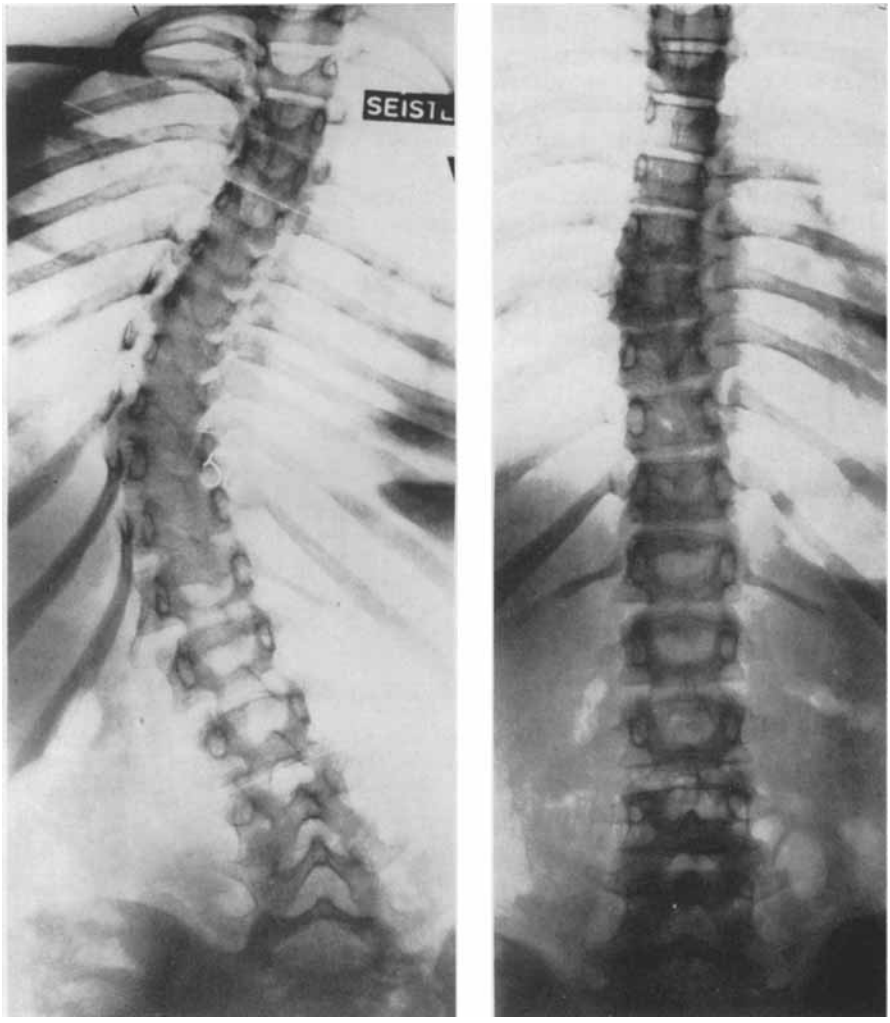

Fig. 16. Human. Scoliosis of 50 degrees in a child aged 10. There was a scar from an abscess extending to the vertebral laminae. a) Radiograph taken one week *after* excision of the scar. b) Radiograph one year after operation. The spine was almost straight.

costo-transverse ligament at several levels of the spine of a growing rabbit or pig causes progressive scoliosis of the same type as is seen in man. This ligament, in transmitting the effect of normal muscle tone to the spine, is of decisive importance to its equilibrium and symmetrical growth.

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