Radiate ligament shortening and idiopathic scoliosis

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ABSTRACT

الأهداف: بحث الدور المحتمل للرباط المتشعع في حالات جنف العمود الفقري المجهول السبب.

الطريقة: صممت هذه الدراسة لدراسة مجموعة من الجثث التي قسمت إلى مجموعتين (مجموعة الدراسة والشاهد). و قد قمنا بدراسة 18 جثة بشرية، 12 منها لذكور و6 لإناث من السلالة القوقازية، بمتوسط عمر 55 عاماً بقسم التشريح، كلية الطب، جامعة الملك سعود، مدينة الرياض، المملكة العربية السعودية خلال الفترة من نوفمبر 2010 إلى فبراير 2012. وتتكون العينة من 15 جثة ذات عمود فقري سليم و3 جثث بها جنف في العمود الفقري. و قد تم تمييز الأشرطة العلوية والسفلية للأربطة المتشععة و قياسها. كما تم فحص جميع الجثث تشريحياً، بالإضافة إلى دراسة الصور الشعاعية الخاصة بالجثث المصابة بالجنف في العمود الفقري.

النتائج: لقد كشفت الدراسة الحالية عن وجود قصر ملحوظ في متوسط طول الأشرطة العلوية بالجانب المقعر من العمود الفقري للجثث المصابة بالجنف في العمود الفقري مقارنةً بطول مثيلاتها بالجثث ذات العمود الفقري السليم، على عكس الأشرطة السفلية التي لم يظهر اختلاف بين متوسط أطوالها.

خاتمة: تقترح هذه الدراسة وجود علاقة محتملة بين قصر الرباط المتشعع مسببات جنف العمود الفقري المجهول السبب.

Objective: To investigate the possible role of radiate ligament in idiopathic scoliosis.

Methods: This study was designed as a case-control study adapted to cadavers. Eighteen human cadavers, 12 males and 6 females of Caucasian race, with a mean age of 55 years were studied at the Department of Anatomy, College of Medicine, King Saud University, Riyadh, Kingdom of Saudi Arabia from November 2010 to February 2012. Among the studied subjects, 15 were with normal spines, and 3 were scoliotic. The upper and lower bands of radiate ligaments were identified and measured. All cadavers were examined grossly. Scoliotic cadavers were also examined radiologically.

Results: The present study revealed that the mean of the lengths of the upper bands of radiate ligaments, on the concave side, in each scoliotic cadaver showed a highly significant shortening compared with that of the upper bands of the corresponding segments in cadavers with normal spines, while no significant change was detected when comparing those of the lower bands to normal values.

Conclusion: The study suggested a possible relationship between radiate ligament shortening and the etiology of idiopathic scoliosis.

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Stability of the vertebral column depends upon dynamic muscular control, however there are also bony and ligamentous static stabilizers. Stability may be compromised by the damage to any of these structures.[1] Ligaments are formed of collagen fibers that are mainly bound together like the strands of a rope, since they must withstand the strain put on them at each joint they span. Importantly therefore, they are very strong when pulled from either ends.[2] Microfailure

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of ligaments begins even before the physiological load range is exceeded, especially when loads are applied and released at specific intervals.[3] Pure ligamentous injury leading to instability may therefore be particularly difficult to diagnose in the absence of gross radiological signs.[1] The costovertebral joints and rib cage play an important role in providing stability of the thoracic spine.[4] Radiate ligaments connect the anterior part of each costal head to the bodies of 2 vertebra and their intervening disc. Superior fibers ascend to the vertebral body above inferior fibers to the body of numbered vertebra. Intermediate fibers, shortest and least distinct, are horizontal and attached to the disc. Surprisingly, in the first, tenth, eleventh, and twelfth ribs, which articulate with single vertebra, the radiate ligament is attached not only to each of the numbered vertebra, but also to the one above.[1] Furthermore, radiate ligaments were also identified in cervical and lumbar regions, suggesting another function of such ligaments rather than only supporting the costal heads, probably controlling lateral flexion and rotation.[5] Scoliosis is a complex 3-dimensional deformity characterized by lateral bending, rotation and hypokyphosis. The majority of the cases are idiopathic with no recognizable etiology.[6] Previous studies showed that transection of the ligaments at the heads of the ribs lead to functional and structural scoliosis in rabbits.[7] The present study aimed to investigate the radiate ligaments anatomy in normal and scoliotic cadavers and their possible role, if any, in idiopathic scoliosis.

Methods. The present study was designed as a quantitative observational case-control study adapted to cadavers. This study has been approved by the Institutional Review Board. Eighteen human cadavers, obtained from the dissecting room of the Department of Anatomy, College of Medicine, King Saud University, Riyadh, Kingdom of Saudi Arabia were studied from November 2010 to February 2012. The sample comprised 12 males and 6 females of Caucasian race, with a mean age of 55 years. Fifteen of them (10 males and 5 females) were with normal spines, and had neither arthritic nor degenerative changes. The remaining 3 cadavers, 2 males (S1 and S2) and 1 female (S3) were scoliotic.

In the thoracic region, the anterior chest wall, organs, the vessels and parietal pleura were removed to expose the vertebra, the ribs, and the ligaments connecting to them. In the cervical and lumbar regions, the muscles, organs, vessels, and nerves were removed, exposing the vertebral bodies with their transverse processes. Special care was taken to remove the *longus colli* muscle in the cervical region, and psoas major muscle in the lumbar region without damaging any of the ligamentous structures. The radiate ligaments were identified by blunt dissection of the underlying adipose tissue. The length of the upper and the lower bands of the radiate ligaments of all cadavers were measured on both sides, using a Vernier caliper. The length of the ligament was defined as the distance between the midpoints of its attachments to the rib and to the vertebra.[8,9] The middle band was ill-defined, and too short to be accurately measured, and thus excluded from the study design. For each scoliotic cadaver, an antero-posterior radiograph was performed. For the scoliotic cadavers, S1 and S3, an additional CT scan was performed. The most affected vertebra called the apical vertebra, as well as, the upper and lower vertebra of the curve were identified. Cobb angle was measured in the scoliotic cadavers antero-posterior radiographs. To measure it, a line was drawn along the edge of the vertebra and extended out. On the upper bone, the line was drawn along the upper edge, and slopes downward according to the angle of the vertebra. On the lowest vertebra, the line was drawn along the lower edge and slope in an upward direction. Perpendicular lines were then drawn from both lines so that they meet each other at the level of the apical vertebra to form the Cobb angle.[10]

The means ± standard deviations of the lengths of radiate ligaments were calculated using Predictive Analytics SoftWare (PASW) version 18 (SPSS Inc, Chicago, IL, USA). We used a 95% confidence level to calculate a confidence interval, which is a range of values approximately the mean, where the "true" (population) mean can be expected to be located with 95% certainty. Student t-test for dependant samples was used to compare the mean lengths of the upper to those of the lower bands of the same side, and to compare the upper and lower bands of one side to the corresponding bands of the other side, in cadavers with normal spines. The means of the lengths of the upper and lower bands of radiate ligaments of both sides in each scoliotic cadaver were calculated, and were compared to those of the corresponding bands in cadavers with normal spines, utilizing Student t-test for dependent samples. Differences were considered significant when $p \leq 0.05$ and highly significant when $p < 0.01$.

Results. In the cadavers with normal spines, the range of the lengths of upper and lower bands of radiate ligaments was 7-11 mm. No significant differences were found when comparing the mean lengths of the upper to those of the lower bands of the same side ,and when comparing the upper and lower bands of one side to the corresponding bands of the other side (**Table 1**). Both bands had an oblique to horizontal attachment. In all scoliotic cadavers, the upper bands of radiate ligaments on the concave side showed shortening (**Figures 1A-1D & Figures 2A & 2B**). The mean of the lengths of the upper bands of radiate ligaments, on the concave side, in each scoliotic cadaver showed a highly significant shortening compared with that of the upper bands of the corresponding segments in normal cadavers ($p<0.01$), while no significant differences were detected when comparing those of the lower bands to normal values ($p>0.05$). The mean lengths of both upper and lower bands of radiate ligaments on the convex side showed a significant shortening compared with normal values in case of S1 and S2 ($p<0.05$), while shortening existed but was non-significant in case of S3 ($p>0.05$) (**Table 2**). The scoliotic cadaver (S1) had a thoracic curve with a compensatory lumbar curve; the thoracic curve extended from T4-T12 with an apex at T9. Cobb angle measured on the CT supine reconstruction view showed a right thoracic curve with rotation and a Cobb angle of 60°, and a left lumbar curve of 50°. There were no structural anomalies in the vertebral column or ribs indicating that the cadaver had a right thoracic with a

Table 1 - Comparison between the mean length (mm) of upper and lower bands of the radiate ligament in normal spine on both sides.

Variables	Upper band		Lower band		*P*-value*
	Mean ± SD	95% CI	Mean ± SD	95% CI	
Left side	9.083 ± 0.875	8.527-9.639	9.458 ± 1.305	8.629-10.287	0.180 (NS)
Right side	9.250 ± 0.754	8.771-9.729	9.375 ± 1.189	8.620-10.130	0.612 (NS)
P-value†	0.339 (NS)		0.772 (NS)		

P-value* - Comparing upper band versus lower band on either side; *P*-value† - Comparing sides regarding either band. NS - non-significant ($p>0.05$); CI - confidence interval

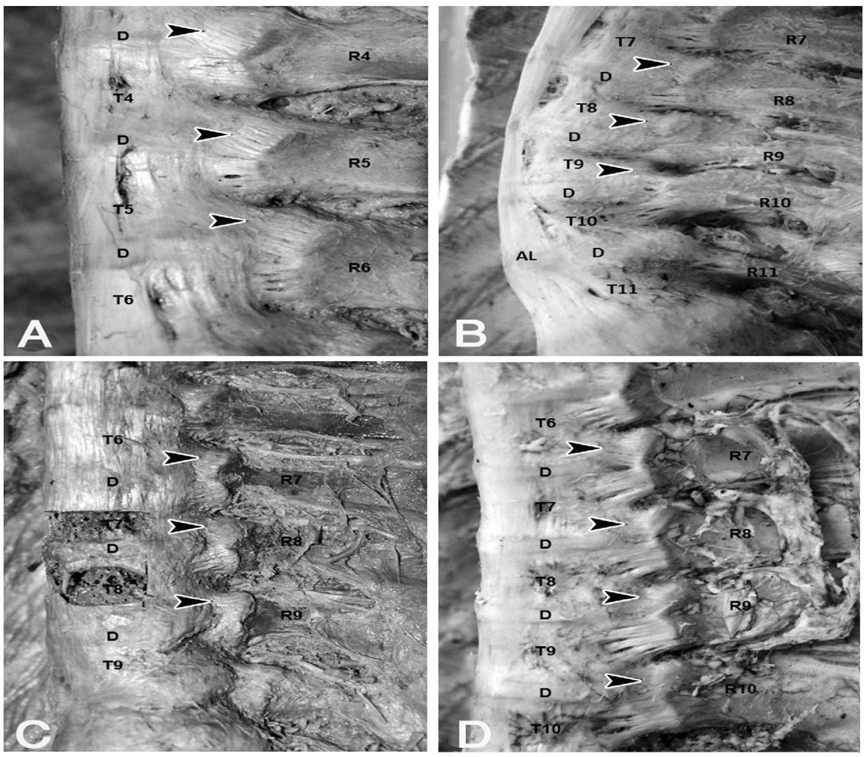

Figure 1 - The upper bands (arrowheads) of radiate ligaments in: **A**) a cadaver with normal spine; **B**) S1; **C**) S2; and **D**) S3. Shortening of the upper bands is marked in scoliotic cadavers. D - intervertebral disc; R - rib; T - thoracic vertebra.

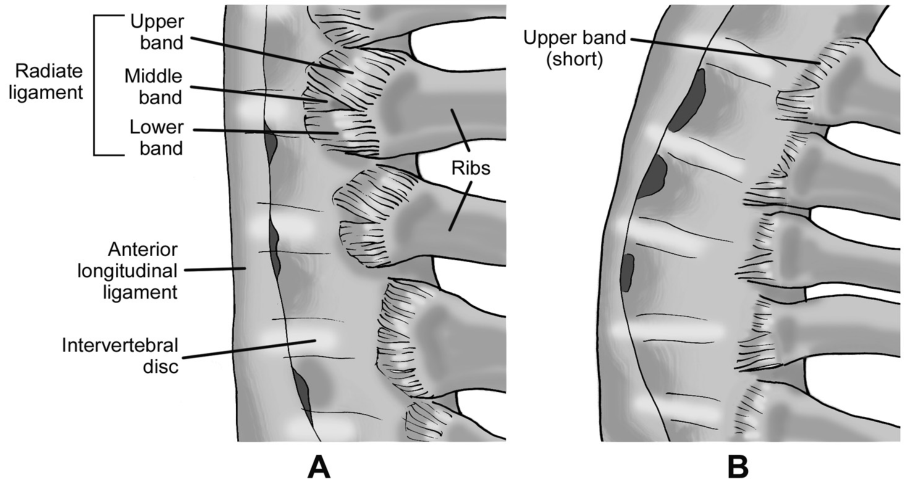

Figure 2 - A diagram illustrating the radiate ligaments in the concave side in: **A**) normal spine; **B**) scoliotic spine.

Table 2 - Comparison of the mean length (mm) of upper and lower bands of the radiate ligament on both sides of the scoliotic cadavers (S1, S2, S3) versus normal values.

Side	Normal	S1		S2		S3	
	Length	Length	*P*-value	Length	*P*-value	Length	*P*-value
Left (concave)							
Upper band	9.083 ± 0.875	4.833 ± 0.683	0.000022*	6.000 ± 1.155	0.004*	5.357 ± 0.802	0.0004*
95% CI	8.527-9.639	4.116 - 5.550		4.162 - 7.838		4.615 - 6.099	
Lower band	9.458 ± 1.305	10.333 ± 1.366	0.194	9.000 ± 1.155	0.862	10.857 ± 0.900	0.078
95% CI	8.629 - 10.287	8.900 - 11.770		7.162 - 10.838		10.025 - 11.689	
Right (convex)							
Upper band	9.250 ± 0.754	7.167 ± 1.602	0.019†	7.195 ± 0.946	0.022†	8.571 ± 2.299	0.453
95% CI	8.771 - 9.729	5.490 - 8.848		5.690 - 8.700		6.445 - 10.697	
Lower band	9.375 ± 1.189	7.667 ± 1.366	0.045†	7.364 ± 1.651	0.041†	8.375 ± 1.652	0.298
95% CI	8.620 - 10.130	6.233 - 9.101		4.737 - 9.991		6.847 - 9.903	

*Highly significant versus normal ($p<0.01$); †significant versus normal ($p<0.05$); CI - confidence interval

compensatory left lumbar idiopathic scoliosis which has not been treated since adolescent age (**Figures 3A & 3B**). The thoracic curve of the scoliotic cadaver (S2) extended from T6 to T12 with an apex at T9. Antero-posterior radiograph showed a right thoracic curve, with rotation and a Cobb angle of 20°. The curve looked idiopathic in nature (**Figure 4**). The thoraco-lumbar curve of the scoliotic cadaver (S3) extended from T6-L3 with an apex at T12. Cobb angle measured 46° with mild rotation. Another curve was detected in the lower lumbar area with an apex at L4 and a Cobb angle of 47° with apparent rotation. No congenital anomalies could be noticed. The curve looked idiopathic in nature (**Figures 5A & 5B**). In all cadavers with normal spines, there was a distinct ligament in the lumbar region. The ligament was attached laterally to the anterior surface of the transverse process, midway between its base and tip. It was fan-shaped with its lower fibers attached to the body of the same vertebra, its upper fibers attached to the vertebra above, and its middle fibers to the disc between the 2 vertebra. This ligament was detected in relation to all lumbar vertebra (**Figure 6**). In the cervical spine, similar fan-shaped ligaments were present in relation to the cervical vertebra from C3-C7 (**Figure 7**).

Discussion. Spinal ligaments are present along the whole length of the spine and functions to limit excessive joint movement, and to provide stability to the spine.[11]

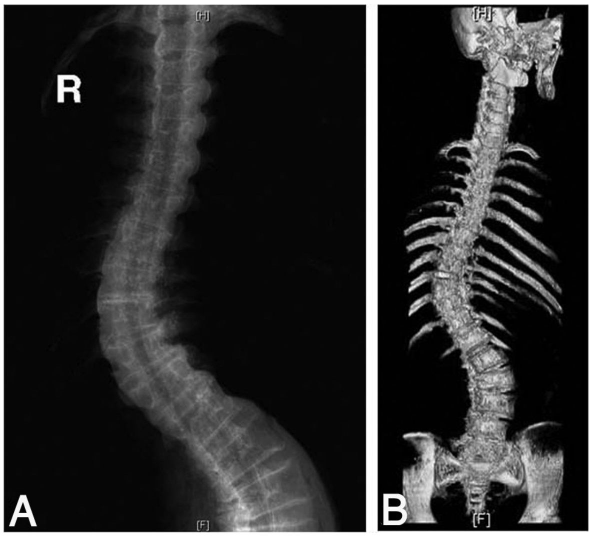

Figure 3 - A radiologic image of the scoliotic cadaver S1 obtained by: **A**) radiograph; **B**) CT scan.

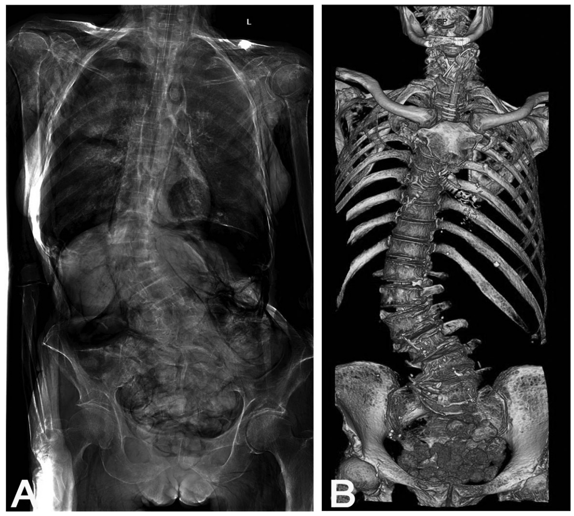

Figure 5 - An image of the the scoliotic cadaver S3 obtained by: **A**) radiograph; **B**) CT scan.

Figure 4 - A radiograph of the scoliotic cadaver S2.

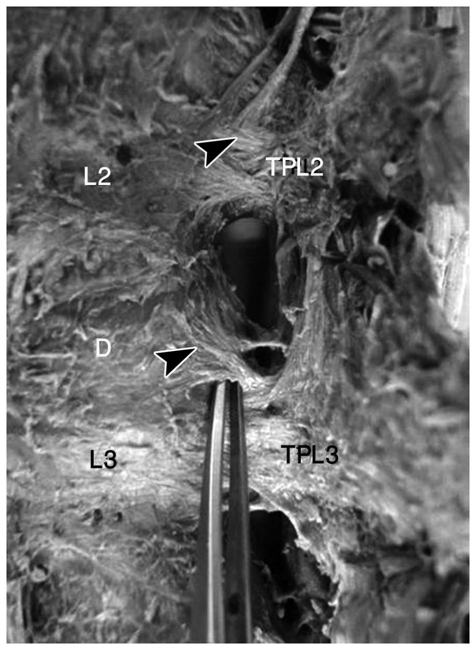

Figure 6 - A radiate ligament in the lumbar region. TP - transverse process; L - lumbar vertebra; D - intervertebral disc; arrowheads - upper band of radiate ligament.

Ligaments passing between the vertebra and the ribs; the superior costotransverse and posterior costotransverse ligaments perhaps are the most important ligaments for active lateral balancing of the spine.[8] However, those ligaments are limited to the thoracic region and cannot explain the rotation deformity observed in scoliosis. Regarding the radiate ligament, it is the only ligament that is attached obliquely or horizontally to the body of the vertebra. Its upper bands are transarticular and connect the costal head to the body of the vertebra above and are identified even in relation to ribs articulating with a single vertebra.[1]

In the present study, a distinct, fan-shaped ligament was detected in the lumbar (**Figure 6**) and

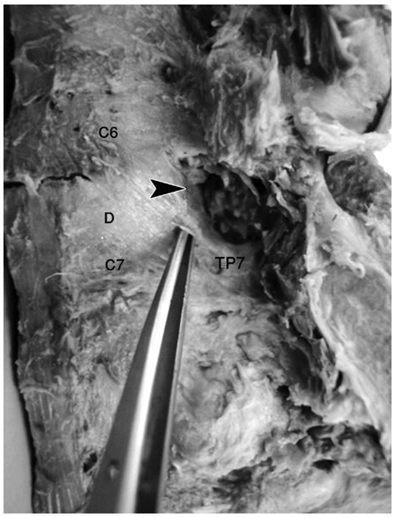

Figure 7 - A radiate ligament in the cervical region. TP - transverse process; C - cervical vertebra; D - intervertebral disc; arrowhead - upper band of radiate ligament.

cervical (**Figure** 7) regions. This ligament connected the transverse process of the vertebra to the bodies of the same vertebra, and the vertebra above and their intervening disc; its lower fibers were attached to the body of the same vertebra, its upper fibers to the body of the vertebra above, and its middle fibers to the disc between the 2 vertebra.

The fact that the part of transverse process, to which the ligament is attached represents the costal element of the vertebra (that is, the part of the bone that forms the rib, in the thoracic region)[12] indicates a resemblance of this ligament to the radiate ligament regarding their attachments. The present observations supported those of Dvorak and Sandler,[13] and Amonoo-Kuofi et al,[5] who identified radiate ligaments in the cervical and lumbar regions. Such findings might suggest another function of radiate ligaments rather than supporting the costal heads, probably controlling the axial rotation of the vertebra.[5]

Scoliosis is a complex 3D deformity characterized by lateral bending, rotation, and hypokyphosis.[14] In a normal spine, the vertebral rotation causes a deformity that is similar to what is seen in scoliosis.[15] Many authors proposed that scoliosis deformities evolve as rotation.[16-20] Adolescent idiopathic scoliosis results from a breakdown of rotation control of the spine. With severe rotation, more strain is applied to the ligaments attached between the vertebra and the ribs. In the immature human spine under load, this torsion produces asymmetric loading of vertebral growth-plates; the resulting growth asymmetry of the vertebral bodies potentiates the torsional deformity to cause progressive idiopathic scoliosis.[20]

The present study revealed that the mean of the lengths of the upper bands of radiate ligaments on the concave side in each scoliotic cadaver, showed a highly significant shortening compared to that of the upper bands of the corresponding segments in cadavers with normal spines, while no significant change was detected when comparing those of the lower bands to normal values. The results of the present study suggest an involvement of the radiate ligament, its upper bands in particular, in idiopathic scoliosis. Shortening of the upper bands of radiate ligament on the concave side of the scoliotic curve might be a possible etiology of such deformity. A previous study[7] showed that transection of the ligaments at the heads of the ribs (including radiate ligaments) lead to functional and structural scoliosis in rabbits. Congenital shortening of the radiate ligament (for example, in collagen disorders), might lead to rotational deformity, which in turn predisposes to the so called idiopathic scoliosis. In accordance with the present suggestion, studies[14,21] have related collagen defect to idiopathic scoliosis.

The present study also revealed that the mean lengths of both upper and lower bands of radiate ligaments on the convex side showed a significant shortening compared to normal values in case of S1 and S2, while shortening was non-significant in case of S3. On the convex side, the shortening of both upper and lower bands could be attributed to the deforming forces of the vertebral bodies pushing on the ribs, suggesting changes secondary to the deformity of the spine. It might be that the prolonged abnormal load, or force exerted by the rotated vertebra on the ribs leads to approximation of the heads of ribs to the vertebra and shortening of the radiate ligaments.

In accordance with the present suggestion, the non-significant shortening of both bands of radiate ligaments observed in case of S3, which might be attributed to the milder rotation in this cadaver compared to the other 2 cadavers. However, such suggestion needs further investigation.

The limitations of this study are the small number of the scoliotic cadavers studied and their old age, which were due to the difficulty encountered by the authors to find such extremely rare condition in cadavers. Therefore, it is recommended that surgeons should look more closely at the anatomy of the radiate ligament during anterior procedures, where the rib head and anterior disc were taken down to increase the flexibility of the spine in scoliosis. Further dissection of anatomic specimens of patients with scoliosis will therefore, be necessary to better describe the anatomy of the radiate ligament. Also, studies on animal models would be helpful to investigate the relation between transection of the upper bands of radiate ligaments and development of scoliosis.

In conclusion, the present study reports on the possible relationship between the radiate ligament and idiopathic scoliosis in human. Shortening of the upper bands of the radiate ligament might lead to rotational deformity of the spine to the other side, which in turn predisposes to idiopathic scoliosis. Shortening of upper and lower bands of radiate ligaments on the convex side might be a consequence of such deformity. Finally, the present anatomic observation might help in understanding the complex 3D deformity of idiopathic scoliosis.

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