An anatomical study of the human lumbar ligamentum flavum

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ABSTRACT

الهدف : إن معرفة الدراسة التشريحية للعمود الفقري خاصة بالنسبة للمنطقة القطنية هام جداً في حالة حقن مُخدر أو مُسكن في المنطقة فوق الجافية. الهدف من هذا البحث هو دراسة التركيب التشريحي والميكروسكوبي للرباط الأصفر.

الطريقة : تم دراسة العمود الفقري لأربعة عشر جثة لرجال طبيعيين تم الحصول عليها من قسم التشريح جامعة الملك فيصل بالدمام. تراوحت أعمارهم بين منتصف العمر ومرحلة الشيخوخة. تم فصل الجزء القطني من العمود الفقري كاملاً لتشريحه. كما تم قياس الإرتفاع والعرض للرباط الأصفر باستخدام القدمة، أيضا تم قياس السُمك باستخدام مسطرة مُدرجة بالملليمترات، ثم أخذ عينات من الرباط الأصفر للقيام بالدراسة الميكروسكوبية للرباط. تم دراسة الرباط بعمل أشعة مقطعية لثلاثين من المرضى لايعانون من مشاكل في العمود الفقري القطني. و قياس العرض والسُمك للرباط الأصفر باستخدام صُور الأشعة المقطعية.

النتائج : أوضحت النتائج أن الرباط الأصفر للناحية اليمنى واليسرى يكون زاوية حادة متجهة إلى الأمام عند تقابلهم في خط المنتصف. وهُو رباط مستطيل وله أربعة حواف وسطحين، ويتصل من أسفل بالحافة العُليا والسطح العُلوي الخلفي للصفيحة السُفلية، وتتصل من أعلى بالحافة السُفلى والسطح الأمامي للصفيحة العُليا. وهي تمتد من الناحية الأنسية الوسطية إلى قاعدة الشوكة ومن الناحية الوحشية الجانبية تمتد حتى الثقب بين الفقرات. وقد وُجد أن ارتفاع هذا الرباط يتراوح بين أربعة عشرة ملليمتر واثنين وعشرين ملليمتر كما وُجد أن العرض يتراوح بين احدى عشر واثنين وعشرين ملليمتر ويتراوح السُمك بين ثلاثة ونصف ملليمتر وستة ملليمترات، وبدراسة الرباط الأصفر ميكروسكوبياً، وُجد أنه يتكون في معظمه من نسيج ضام مطاط مُرتب طولياً مع وجود بعض الحزم الرقيقة من الألياف الكولاجينية الغرائية، أوضحت دراسة الرباط بالأشعة المقطعية وجود زيادة طفيفة في قياس العرض والسُمك للرباط على الجثة عند مقارنتها بالأشعة المقطعية وهذة الزيادة لم يثبت أنَّ لها دلالة إحصائية.

خاتمة : يُعتبر الرباط الأصفر علامة أو دليل تشريحي هام للقيام بتخدير آمن فوق الجافية ولهذا يقترح ادخال الإبرة خلال الجزء الأنسى الوسطى السُفلي للرباط الأصفر بمقدار قليل من الناحية الوحشية الجانبية من خط المنتصف.

Objectives: A detailed investigation of the gross and microscopic anatomy of ligamentum flavum.

Methods: Material included 14 lumbar vertebral columns obtained from the Anatomy Department, King Faisal University, Dammam during the period between January 2005 and January 2006. Height, width, and thickness of ligamenta flava were measured. A microscopic study was also performed. Computed tomography scan was carried out on the lumbar vertebrae of 30 patients for measuring the ligamentum flavum.

Results: The anatomical results showed that the right and left ligamenta flava join in the midline forming an acute angle with a ventral opening. The ligamentum flavum is rectangular and has 4 borders and 2 surfaces. It is attached inferiorly to the superior edge and the postero-superior surface of the lamina below. It is attached superiorly to the inferior edge and the antero-inferior surface of the lamina above. Its height ranges from 14-22 mm. The width of its lower part ranges from 11-23 mm, and the thickness ranges from 3.5-6 mm. The histological results revealed that it is comprised chiefly of elastic fibres and some collagen fibres.

Conclusion: The information reported in this study is of clinical value in the practice of lumbar epidural anesthesia or analgesia. Epidural puncture will be best performed through the lower and medial portion of the ligamentum flavum slightly lateral to the midline.

Neurosciences 2008; Vol. 13 (1): 11-16

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Received 4th April 2007. Accepted 15th July 2007.

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Formerly, little attention has been given to the lumbar segment of the vertebral column, both in considering the anatomy and physiology of the normal vertebrae and in elucidating the pathological anatomy and pathophysiology.[1-3] Deformation of the vertebral column that tends to lengthen the ligamenta flava is resisted by these ligaments, which have an elastic force. Therefore, it would take greater muscular action to produce such deformation activity, however, the return to neutral action would require less muscular action if the ligamenta flava were not present.[4] The apparent functional importance of this ligament to the integrity of the vertebral column and the frequency with which they are encountered surgically justifies consideration of its anatomy in detail.[4] In perioperative pain treatment of the lower extremities, lumbar analgesia and epidural anesthesia have become more important. To identify the epidural space, the loss of resistance technique is used by penetrating the ligamentum flavum, whose exact anatomy is still controversial.[5] The aim of this study was to make a detailed investigation of the gross and microscopic anatomy of the ligamentum flavum. The anatomic observation reported in this study is of clinical value in the practice of lumbar epidural anesthesia.

Methods. The material of this study included 14 normal cadaveric lumbar vertebral columns obtained from the Anatomy Department, King Faisal University in Saudi Arabia during the period between January 2005 and January 2006. All the specimens were males. The inclusion criteria were normal cadaveric lumbar vertebral column specimens obtained from males. Their ages ranged from middle to old age. Dissections were carried out by removing the lumbar vertebral column in toto from the bodies of the cadavers. Superficial tissues were removed by dissection to expose the vertebral bodies, pedicles, transverse processes, and spines. The pedicles were sectioned by an electric saw, dividing the vertebral column into 2 pieces, the anterior, which was dissected, formed by the vertebral bodies, their pedicles, and intervertebral discs, and the posterior that consists of the articular, transverse, and spinous processes with their ligaments, the vertebral laminae with the ligamenta flava and the lumbar dural sac and its contents. The spinal cord and its meninges were removed to expose the ligamenta flava, which were photographed and measured as follows: Height and width were measured using a vernier caliber, and the thickness of the ligament was measured using a millimeter ruler. To measure the thickness, a transverse section near the lower border of the ligamentum flavum was carried out. Various portions of the 14 gross specimens were chosen for microscopic study. Fixation was carried out using 10% formalin. Decalcification by EDTA was performed at the attachment site of the ligamenta flava with the lamina. Standard paraffin block sections were cut. Staining techniques employed, consisted of Masson trichrome and the orcein connective tissue stain for the specimen studied.[6] Sections were examined by light microscopy.

Computed tomography (CT) (soft tissue window) scan on the lumbar vertebrae was carried out on 30 patients (18 males and 12 females) complaining of problems far away from the L3-L4 region that was studied. Informed consent was obtained from each subject after approval of the local human ethics committee. The exclusion criteria for the CT was different diseases affecting the L3-L4 region. The lumbar region studied in this work was free from any diseases. The CT scans were obtained with a Somatom Plus 4 (Siemens). Slice thickness of 4 mm was generated. The scans were oriented axially to the spinal disc level. The images were studied in bone and soft tissue window.[7] Width and thickness of the ligamentum flavum were measured by CT.

Data were entered on SPSS for windows program, release 11.5 (SPSS, Chicago, III) for statistical analysis. Means and standard deviations of the studied parameters were obtained. Using the student's t test, comparison of the width and thickness of the ligamenta flava measured on cadavers and by CT on patients was carried out. The level of significance was set to $p<0.05$.

Results. *Anatomical results.* In each lumbar interspace, there are 2 ligamenta flava, the right and the left, which join in the midline forming an acute angle with a ventral opening (**Figure 1**). The ligamentum flavum is rectangular and has 4 borders and 2 surfaces. It is attached inferiorly to the superior edge and the postero-superior surface (the upper part of the external surface of the lamina below). Some deep (ventral) fibres are attached to the antero-superior surface of the lamina below. Thus, the ligamenta flava is considered to be formed of 2 parts: a superficial part, which inserts into the upper border and the postero-superior surface of the lamina below, and a deep part, which inserts into the antero-superior surface of the lamina below. The ligamentum flavum is attached superiorly to the inferior edge and the anteroinferior surface (the lower part of the internal surface) of the lamina above (**Figures 1 & 2**). The medial border of the ligamenta flava corresponds to the base of the spinous process and to the corresponding border of the opposite ligamentum flavum. The lateral border extends as far as the intervertebral foramen forming the entire posterior boundary or roof of the foramen (**Figure 2**). It turns dorsally outside the foramen and fuses with the capsule of the articular facets. The direction of fibres of the superficial part of the ligamentum flavum is upwards and medially towards the spine and is more oblique in its lateral portion close to the intervertebral foramen, and the direction of the deep fibres is craniocaudal. The internal surface of the ligament limits the vertebral canal and is separated from the dura mater by the epidural space. The direction of the deep fibres is craniocaudal (**Figure 1**). The external surface is related to the internal

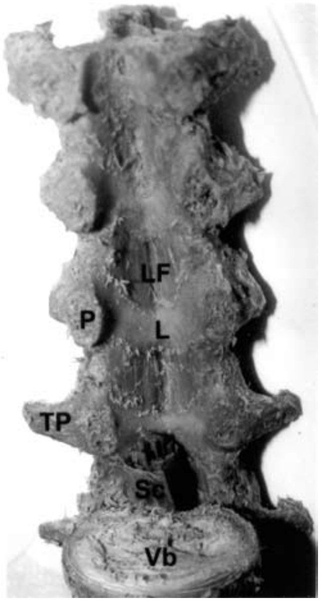

Figure 1 - Photograph of the lumbar segments of the vertebral column showing the posterior wall of the vertebral canal. The deep fibres of the ligament are directed cranio-caudally. LF - ligamentum flavum, L - lamina, TP - transverse process, P - pedicle, M - muscles, Vb - Vertebral body, SC - Spinal cord covered by meninges.

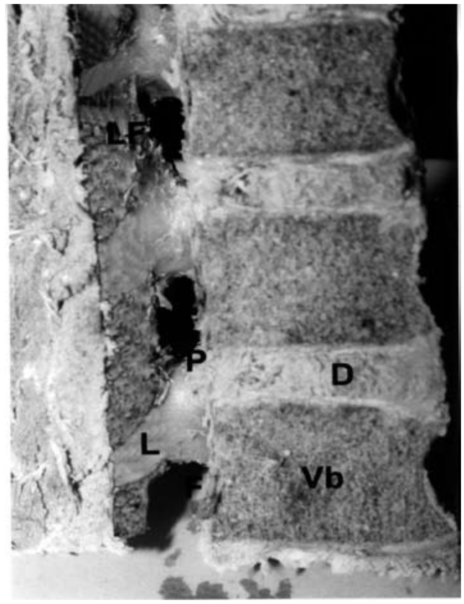

Figure 2 - Photograph of a longitudinal section of the lumbar segments of the vertebral column showing the internal surface of the vertebral canal. The ligamentum flavum extends laterally to the inter-vertebral foramen forming its posterior boundary. LF - ligamentum flavum, L - lamina, Vb - vertebral body, P - pedicle, D - intervertebral disc, F - intervertebral foramen.

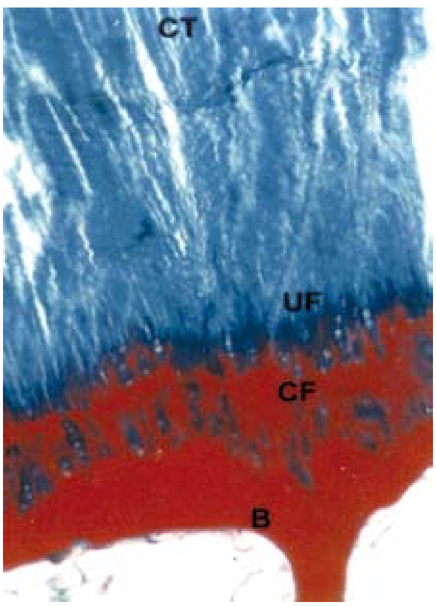

Figure 3 - Micrograph of a longitudinal section of the ligamentum flavum at the site of its attachment to the lamina. It shows penetration of the connective tissue fibres into the bone matrix at the edge of the lamina. B - bone, CF - calcified fibro-cartilage, UF - uncalcified fibrocartilage (Masson Trichrome x 400).

surface of the vertebral lamina in its superior portion and with the sacrospinal muscles in its inferior portion, but it does not give origin or insertion to these muscles. The muscles separate easily from the ligamenta flava and there is a thin layer of loose areolar fibrous and fatty tissue separating these structures. There is a similar tissue layer on the ventral surface of the ligament separating it from the underlying dura mater (**Figures 1 & 2**). The height of the ligamentum flavum ranges from 14-22 mm with a mean of 16.4±5.2 standard deviation (SD). The width and thickness of its lower part ranges from 11-23 mm with a mean of 18.7±3.4 SD, and 3.5-6 mm with a mean of 4.5±0.8 SD.

Histological results. As the ligamentum flavum approaches its laminal insertion, it has uncalcified and then calcified fibrocartilaginous features. Connective tissue fibres could be demonstrated penetrating the bone (**Figure 3**). The ligamenta flava are made up chiefly of elastic connective tissue fibres longitudinally arranged with some thin bundles of collagen fibres and few spindle shaped fibroblasts. The elastic fibres are thinner than the collagen fibres (**Figure 4a**). In the older age specimens, some fragmentation of elastic fibres was observed (**Figure 4b**). Capillaries and very small thin walled blood vessels were not numerous and seen irregularly dispersed. No nerve trunks or endings were seen in the ligamentum flavum.

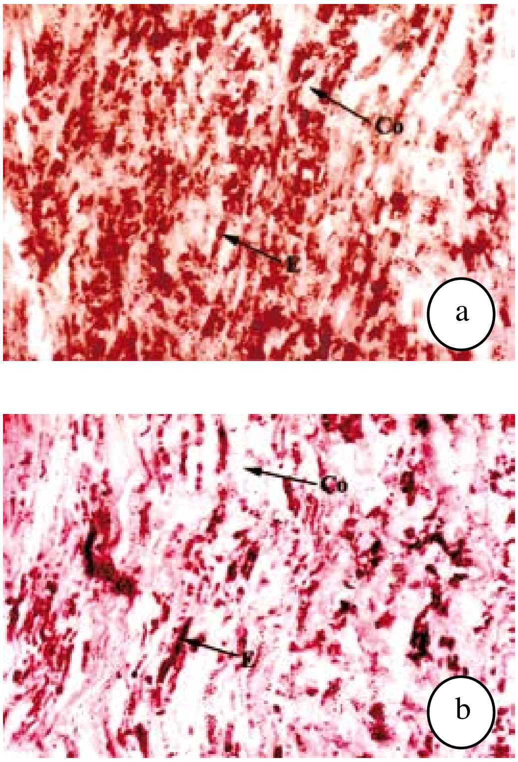

Figure 4 - Micrograph of a longitudinal section of the ligamentum flavum in an **a**) adult specimen, showing large amount of elastic fibres (E) (brick red) dispersed between few collagen fibres (Co) (pale), **b**) in an aged specimen, showing an increase in the amount of the Co with few E in between (Orcein x 400).

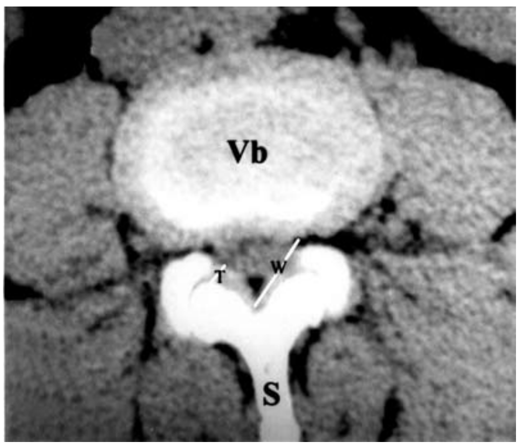

Figure 5 - Metric analysis of the ligamentum flavum at spinal disc level L3-L4 in the axial plane positioned scans (CT soft tissue window). The white lines indicate the measured distances (width and thickness). W - width, T - thickness, Vb - vertebral body, S: spine.

Radiological results. By CT scan, the width and thickness of the ligamenta flava range from 13-22 mm with a mean of 16.7±2.6 SD, and 3.7-5.8 mm with a mean 4.3±0.6 SD using soft tissue window (**Figure 5**). The ligamenta flava appeared to be slightly wider and thicker when measured on cadavers in comparison with CT measurements. These differences were not statistically significant using student's t-test ($p<0.05$) (thickness: 1.69, width: 2.34).

Discussion. In this study, it was found that the ligamenta flava is formed of 2 layers: superficial and deep. This observation is consistent with Viejo-Fuertes et al.[3] He stated that the fibres of the superficial and deep layers run in opposite directions. Zarzur,[1] Ramsy,[4] Olszewki et al,[8] and Grifka et al,[9] found that the lower border of the ligamenta flava is inserted on the upper border and part of the external surface of the underlying vertebral lamina. Olszewki et al,[8] and Viejo-Fuertes et al[3] observed that the ligamenta flava has also a deep slip, which is inserted into the antero-superior surface of the caudal lamina. Grifka et al,[9] also noticed that the insertion of the ligamenta flava on the caudal lamina covers the ventral and dorsal surfaces as it is formed of superficial and deep parts. Grifka et al,[9] suggested that the ligamentum flavum can be divided into: pars interspinalis, which is adjacent to the spines, pars interlaminar, which starts at the laminae and constitutes the target area for flavotomy in its lateral section, and pars capsularis, which merges into the capsular structures of the facet. In the current study, it was found that the ligamenta flava is attached superiorly to the inferior edge and the antero-inferior surface of the lamina above, close to its inferior edge. This finding was similar to Ramsey.[4] However, Zarzur[1] stated that the upper border of the ligament is inserted on the intersection between the inferior two-thirds and the superior one-third of the internal surface of the adjacent superior lamina. Yong-Hing et al,[2] found that the upper attachment of the ligament is to the anterior surface of the lamina above, approximately halfway from its upper and lower edges. This observation was different from the findings of the present study. Grifka et al,[9] found that the ligamentum flavum rises from the ventral surface of the lamina above. The ventral convexity of the ligamentum flavum at the inter-vertebral foramen actually narrows the antero-superior diameter of the foramen. This may be further narrowed as hypertrophic marginal changes of the articular facets develop with advancing age. The nerve root always lies in close proximity to the capsular portion of the ligamentum flavum.[3] Ramsy[4] stated that laterally the ligamentum flavum constituted a strong anterior reinforcement of the ligaments of the facets as was noticed in the present study.

Dimensions of the ligamenta flava have been considered to be of great interest especially regarding its thickness. The concept that hypertrophy of the ligamenta flava existed and is of clinical significance, has received little attention. In this study, the height, width, and thickness of 14 specimens were measured on cadavers using vernier caliber. They ranged between 14-22 mm for height, 11-23 mm for width, and 3.5-6 mm for thickness. The width and thickness were measured also by CT and ranged between 13-22 mm for width and 3.7-5.8 mm for thickness in the L3-L4 level. Zarzur[1] found that the ligamentum flavum is 13-20 mm in height and 12-22 mm wide, and its thickness ranges from 3-5 mm. He stated that the tip of a needle with a bevel less than 3 mm long will only lie in the ligamentum flavum and the injection of air or anesthetic solution will be impossible.

Schulte et al,[7] highlighted that as the spinal canal is small, it is useful to estimate the sizes and measurements of the anatomical structures lying nearby. The neurosurgeon usually opens the ligamentum flavum when entering the vertebral canal dorsally. Therefore, knowledge of the measurements of this ligament is important to avoid injury of structures lying underneath, such as the nerve roots and myelin. Park et al,[10] mentioned that the mean thickness of the ligamentum flavum was 4.44 mm (range 3.4-5 mm) in lumbar spinal stenosis, and decreased to 2.44 mm (range 1.8-4 mm) in lumbar disc herniation.

Yong-Hing et al,[2] stated that when the width of the lamina is increased in spondylosis and the inter-laminar space becomes small, the distance from origin to insertion of the ligamentum flavum is reduced. It contracts and thickens causing entrapment of the cauda equina or the nerve roots. Also in subluxation of the posterior articular joints, the upper edge of the superior articular process comes to lie near the pedicle above. The portion of the ligament attached to this process and to the pedicle becomes shorter and it thickens. In this way, it may entrap the nerve exiting at this level. To release the entrapment caused by marked narrowing, removal of the laminae and separation of the lateral extension of the ligamenta flava is carried out surgically.[10] It was reported that gross thickening of the ligamentum flavum has occurred in patients with herniated lower lumbar discs as the protruded lumbar intervertebral disc commonly compressed the nerve root against the capsular portion of the ligamentum flavum.[10] The role of the ligamenta flava in nerve root compression syndromes in the lumbar area has been also considered by Park et al.[10] Back pain and sciatica due to hypertrophy of the ligamenta flava was observed. Thickened ligamentum flavum are often found in conjunction with degenerative disease, aging and spinal stenosis at multiple levels and should not be ignored as a possible major contributing factor to the patient's symptoms of nerve root compression. Surgical treatment includes the removal of the whole thickened ligamentum flavum to relieve the pain felt due to its hypertrophy.[11]

Knowledge of the width of the ligamentum flavum is also important. Failure of continuous epidural anesthesia may be due to a transforaminal passage of the catheter through an intervertebral foramen into the paraspinal space.[12] Ramsey[4] indicated that the fibre direction was essentially longitudinally in the interlaminar portion and was slightly oblique downward and laterally in the capsular portion. Grifka et al,[9] proved that in all lumbar levels, there is a change in the direction of pars interlaminar fibers of the ligamentum flavum. The direction of its ventral fibers are always craniocaudal, while its dorsal fibers are craniomedial to caudolateral at an angle between 15-30 degrees to the midline. These findings were consistent with the current study.

These data represent important prerequisites for a selective, gentle, and safe intra-operative procedure for discotomy. Although most texts consider the ligaments to be paired and essentially separated in the midline, as was observed in this current study, however, Williams et al,[13] consider each ligament to extend from the roots of the articular process on one side to the opposite side, and state that the halves are to a certain extent united in the midline. Viejo-Fuertes et al,[3] stated that its structure is unique for a ligament because of the predominance of elastic fibres as was demonstrated in the current research. It was stated that its innervation grows poorer with increasing degeneration.[3] In the older age specimens investigated in the current study, some fragmentation of elastic fibres with increase in the amount of collagenous tissue was observed due to substitution fibrosis. Herzog[14] demonstrated that this fragmentation and fibrosis is associated with mucoid swelling and hyalinization of the inter-elastic fibrous connective tissue. Postacchini et al,[15] mentioned that the ligamenta flava undergoes slight fibrotic and chondrometaplastic changes with aging. Schrader et al,[16] illustrated the role of histological changes of the ligamentum flavum for the etiology of lumbar spinal stenosis. In lumbar spinal stenosis, almost all of the ligaments of the patients showed fibrosis, calcification, and decrease in the elastic/collagenous fiber ration. A significant correlation between histological changes and age was found. Yong-Hing et al,[2] postulated that in spondylosis, the elastic content decreases and the ligament becomes more rigid. Ossification of the ligamentum flavum usually presents with myelopathy due to spinal stenosis. Its etiology has been associated with trauma, ankylosing spondylitis, hyperthyroidism, and deposition of calcium pyrophosphate crystals.[17-21]

Avrahami et al[22] demonstrated that the calcification of the ligamenta flava of the lumbosacral spine is associated with protrusion of the intervertebral disc also. Specchia et al,[23] and Li et al,[24] stated that there are degenerative changes in the ligamentum flavum occurring in lumbar spine stenosis. In patients with spinal stenosis, these authors demonstrated that in the ligamentum flavum, there is hypertrophic chondrocytes with osteoblast-like activity, which could be the cause of the ossification of the ligamentum flavum.

Zarzur[1] stated that the epidural puncture will be safer if one directs the needle to reach the epidural space as close as possible to the vertex of the angle formed by 2 adjacent ligamenta flava. In this site, accidental perforation of the dura mater is unlikely to occur.

The ligamentum flavum is a crucial anatomical landmark for the safe performance of epidural anesthesia. Lirk et al,[5] recorded ligamentum flavum midline gaps in some embalmed cadavers. In the midline approach, the surgeon should not always depend on the presence of the ligamentum flavum as a barrier when performing epidural needle puncture, as there may be midline gaps in some patients. The information reported in this study showed that epidural puncture is better performed through the lower and medial portion of the ligamentum flavum slightly lateral to the midline. Conducting prospective research on the effect of thickened ligamentum flavum in case of degenerative disease or aging as a possible contributing factor to the patient's symptoms of nerve root compression should be considered in future projects.

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