MORPHOMETRIC STUDY OF THE AREOLAR SPACE BETWEEN THE GREAT VESSELS AND THE LUMBAR SPINE

ESTUDO MORFOMÉTRICO DO ESPAÇO AREOLAR ENTRE OS GRANDES VASOS E A COLUNA LOMBAR

ESTUDIO MORFOMÉTRICO DEL ESPACIO AREOLAR ENTRE LOS GRANDES VASOS Y LA COLUMNA LUMBAR

Luis Marchi[1,2]; Leonardo Oliveira[2]; Rodrigo Amaral[2]; Fernanda Fortti[2]; Luiz Pimenta[2,3]; Nitamar Abdala[1]

ABSTRACT

Objective: This work aims to study the areolar space anterior to the lumbar spine, and also the positioning of the large vessels focusing a lateral approach. Methods:This is a morphometric study of 108 cases based on T2 weighted-MRI images in the supine position. The following measurements were performed: lumbar and segmental lordosis; anteroposterior disc diameter; space between the disc/vertebral body and the vessels; bifurcation between the abdominal aorta and the common iliac veins confluence in relation to the lumbar level. Results:The areolar space with respect to the iliac veins, and with the vena cava increased cranially ($p<0.001$), starting from average 0.6mm at L4-L5 and reaching 8.4mm at L2, while the abdominal aorta showed no increase or decrease pattern across the different levels ($p=0.135$) ranging from 1.8 to 4.6mm. The diameter of the discs increased distally ($p<0.01$) as well as the lordosis ($p<0.001$). The disc diameter was 11% larger when compared to the adjacent vertebral bodies ($p<0.001$) and that resulted in a smaller distance of the vessels in the disc level than in the level of the adjacent vertebral bodies ($p<0.001$). The aortic bifurcation was generally ahead of L4 (52%) and less frequently at L3-L4 (28%) and L4-L5 (18%). The confluence of the veins was usually at the L4-L5 level (38%) and at L5 (37%), and less frequently at L4 (26%). Conclusions: There is an identifiable plane between the great vessels and the lumbar spine which is particularly narrow in its distal portion. It is theoretically feasible to reach this plan, handle the anterior complex disc/ALL and protect the great vessels by lateral approach, however, it is challenging.

Keywords: Blood vessels; Aorta; Venae cavae; Lumbosacral region; Lordosis; Orthopedics; Magnetic resonance imaging; Radiology.

RESUMO

Objetivo: Estudar o espaço areolar localizado anteriormente à coluna lombar e também o posicionamento dos grandes vasos com enfoque em abordagem lateral. Métodos: Estudo morfométrico com 108 casos com base em exames de ressonância magnética com ponderação T2 em posição supina. Foram realizadas as seguintes medidas: lordose lombar e segmentar; diâmetro discal anteroposterior; espaço entre o disco/corpo vertebral e os vasos; bifurcação da aorta abdominal e confluência das veias ilíacas comuns em relação ao nível lombar. Resultados:O espaço areolar com relação às veias ilíacas e à veia cava aumentou no sentido cranial ($p < 0,001$), partindo de média de 0,6 mm em L4-L5 e chegando em 8,4 mm em L2, e a artéria aorta abdominal não apresentou padrão ao longo dos diferentes níveis ($p = 0,135$), variando de 1,8-4,6 mm. O diâmetro dos discos aumentou distalmente ($p < 0,01$), assim como a lordose ($p < 0,001$). O diâmetro discal foi 11% superior ao dos corpos vertebrais adjacentes ($p < 0,001$) e isso refletiu na menor distância dos vasos no nível discal do que no nível dos corpos vertebrais ($p < 0,001$). A bifurcação aórtica estava geralmente à frente de L4 (52%) e com menos frequência, em L3-L4 (28%) e L4-L5 (18%). A confluência das veias foi, em geral, no nível de L4-L5 (38%) e de L5 (37%), e menos frequentemente em L4 (26%). Conclusões: Existe um plano identificável entre os grandes vasos e a coluna lombar, que é especialmente estreito em sua porção distal. Através de acesso lateral é teoricamente factível, porém desafiador, atingir este plano, manipular o complexo anterior do disco/LLA e proteger os grandes vasos.

Descritores: Vasos sanguíneos; Aorta; Veias cavas; Região lombossacral; Lordose; Ortopedia; Imagem por ressonância magnética; Radiologia.

RESUMEN

Objetivo: El trabajo tiene como objetivo estudiar el espacio areolar situado anteriormente a la columna lumbar y también el posicionamiento de los grandes vasos con enfoque de abordaje lateral. Métodos: Estudio morfométrico de 108 casos basados en MRI con ponderación T2 en la posición supina. Se realizaron las siguientes mediciones: lordosis lumbar total y segmentaria; diámetro anteroposterior del disco; espacio entre disco/cuerpo vertebral y los vasos; bifurcación de la aorta abdominal y la confluencia de las venas ilíacas comunes en relación con el nivel lumbar. Resultados: El espacio areolar con respecto a las venas ilíacas y la vena cava inferior aumentó cranealmente ($p < 0,001$), a partir de un promedio de 0,6 mm en L4-L5, llegando a 8,4 en L2, y la aorta abdominal no ha presentado un patrón a lo largo de los diferentes niveles ($p = 0,135$) que van desde 1,8 a 4,6 mm. El diámetro de los discos aumentó distalmente ($p < 0,01$) así como la lordosis ($p < 0,001$). El diámetro del disco fue 11% mayor que el diámetro de los cuerpos vertebrales adyacentes ($p < 0,001$) y esto resultó en la distancia más corta de los vasos en el nivel del disco que en el nivel de los cuerpos vertebrales ($p < 0,001$). La bifurcación aórtica fue en general por delante de L4 (52%) y con menor frecuencia en L3-L4 (28%) y L4-L5 (18%). La confluencia de las venas fue generalmente en L4-L5 (38%) y L5 (37%), y menos frecuentemente en L4 (26%). Conclusiones: Hay un plano identificable entre los grandes vasos y la columna vertebral lumbar que es especialmente estrecho en su parte distal. En teoría, es posible alcanzar este plan, manejar el complexo anterior disco/LLA y proteger los grandes vasos por abordaje lateral, sin embargo, es un desafío.

Descriptores: Vasos sanguíneos; Aorta; Venas cavas; Región lumbosacra; Lordosis; Ortopedia; Imagen por resonancia magnética; Radiología.

1. Universidade Federal de São Paulo, São Paulo, SP, Brazil
2. Instituto de Patologia da Coluna, São Paulo, SP, Brazil
3. University of California San Diego - UCSD, San Diego, CA, USA

Study conducted at the Department of Imaging Diagnostics, UNIFESP
Correspondence: Luis Marchi, Rua Vergueiro, 1421, cj 305, 04101-000, São Paulo, SP, Brazil luismarchi@gmail.com

http://dx.doi.org/10.1590/S1808-185120151404152843 Received on 08/04/2015, accepted on 10/23/2015.

INTRODUCTION

Although iatrogenic vascular lesions do not occur very often during lumbar spine surgery (0.017% to 0.14%), they can be considered the most devastating complication arising from intervertebral disc surgery, and have a very significant mortality rate, reaching as high as 65%.[1] The major vessels include the abdominal aorta, the inferior vena cava, and the common iliac arteries and veins located immediately anterior to the lumbar spine. These structures, especially the veins in a position in front of and juxtaposed to the lumbar spine, are vulnerable to lacerations during surgeries that involve the intervertebral discs.

As is well-documented in the literature,[2–4] discectomy and intervertebral fusion performed on the lumbar spine via lateral transpsoas approach preserves the complex in front of the apophyseal ring/anterior longitudinal ligament. As a result, it does not require manipulation, and generally does not place at risk the large vessels located immediately in front of this disc/ligament complex. However, a new indication was recently incorporated into lateral access approaches: reconstruction in the sagittal plane using hyperlordotic spacers.[5,6] According to the reports, it is necessary to mobilize the vertebral segment through resection of the anterior discal complex, in order to gain segmental angulation.

The vascular anatomy anterior to the lumbar spine has been studied in terms of its implications mainly in relation to an anterior[7] or posterior[8] approach. In the area of the lateral transpsoas approach, despite partial analyses or case reports including the great vessels,[9–14] the most studied anatomy is that of the lumbar plexus in relation to the lumbar discs.[14–20] However, there is no study of the distribution of the great vessels relating the space between them to the anterior aspect of the lumbar spine.

The objective of this article is to study the placement of the great vessels and the distribution of the areolar space in the lumbar spinal region, with a focus on the safety of a lateral approach to the anterior disc complex.

METHODS

We studied sagittal and axial slices of T2-weighted magnetic resonance imaging (MRI) exams of the lumbar spine, selected from the DICOM archive of our institution. Exclusion criteria: arthrodesis of the lumbar spine, more or less than five lumbar vertebrae, deformities like scoliosis (angle greater than 10°); hyperkyphosis, spondylolisthesis, collapsed intervertebral discs or extruded herniated disc, poor image quality (impossible to distinguish the vessels), and exams with slices spaced greater than 3 mm. 108 test cases were selected. The average age was 51 years (standard deviation 16, confidence interval 48 – 54) and 60% of the subjects were male.

The measurements were determined using the OsiriX (Pixmeo, Switzerland) program. To reduce interobserver variability, the measurements were reviewed by two authors. Because lateral access to the lumbar spine is only performed between the thoracolumbar discs above L4L5,[3] although the mobilization procedure for the anterior portion of the disc has been described for the more distal discs of the lumbar spine,[5] the distance measurements were analyzed in the region located between the L4L5 discs and the L2 vertebra. In this study, the measurements acquired were:

1. Lumbar level (axial correspondence in relation to the specific intervertebral disc or vertebral body) where the division/confluence of the great vessels occurs (Figure 1): Division of the abdominal aortic artery (AAA), Confluence of the left common iliac vein (LCIV) with the right common iliac vein (RCIV).
2. Axial distance ("areolar space", shortest distance in millimeters between two referenced points) between the anterior edge of the lumbar spine (vertebral body or intervertebral disc) and the great abdominal vessels (Figure 2): AAA: [Left Iliac Artery (LIA), Right Iliac Artery (RIA)], Inferior Vena Cava (IVC): LCIV, RCIV.
3. Dimensions of the lumbar spine (largest segment of the referenced structures in millimeters): Anteroposterior diameter of the intervertebral disc at the middle axial level of the intervertebral disc,

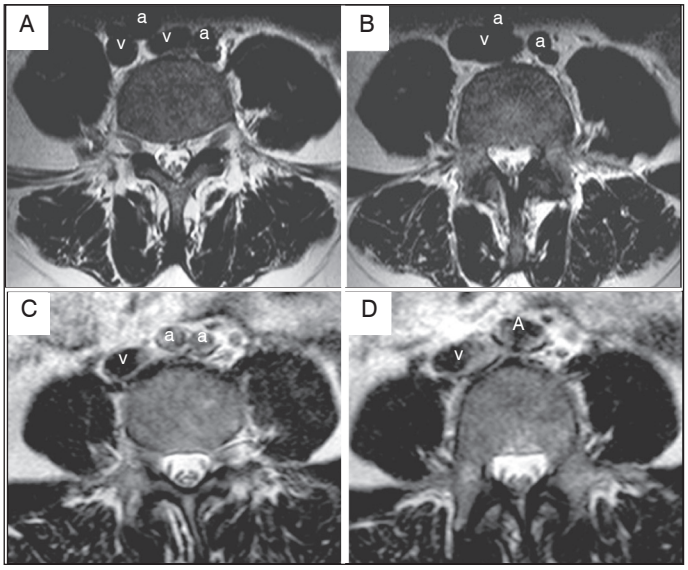

Figure 1. Example of the identification of the great vessel, divided or unified. (A) Common iliac veins (V) still separated, and (B) inferior vena cava (V) as a single vein (C) Common iliac arteries (A) already bifurcated, and (D) the abdominal aortic artery (A) as a single vessel.

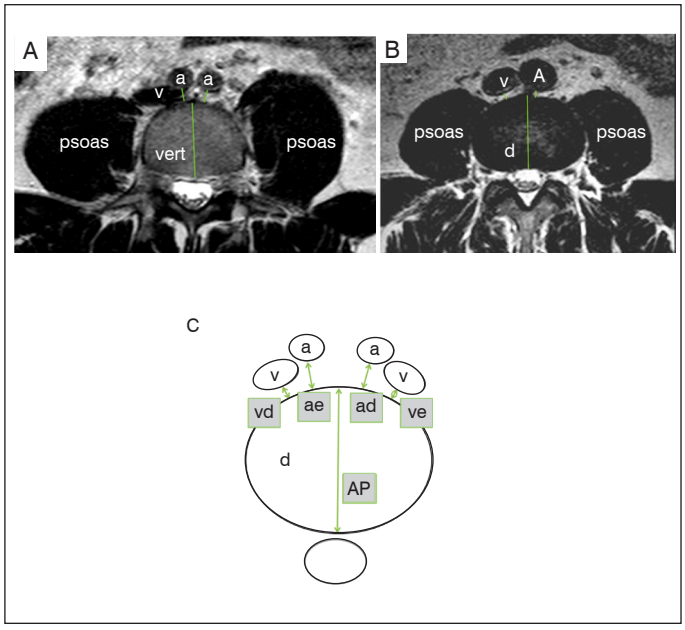

Figure 2. Example of the measurement of the areolar space and the anteroposterior dimension (green lines) in the axial cut. (A) At the level of the vertebral body (vert), the left and right iliac arteries (a) and the abdominal vena cava (V) are evident. Note that there is no areolar space between the spine and the vein, while the space between the spine and the arteries is indicated by the green lines. (B) At the level of the vertebral disc (d), the aortic artery (A) and the abdominal vena cava are in evidence. (C) Schematic representation of the measurements of the areolar space in relation to the right iliac vein (rv), the left iliac vein (lv), the right iliac artery (ra) and the left iliac artery (la), and the anteroposterior diameter of the disc (AP).

Anteroposterior diameter of the vertebral body at the subpedicular axial level of the vertebral body

4. Angulation of the lumbar spine (in degrees, at the sagittal median level) (Figure 3): Segmental lordosis (sLL) – the angle between the upper plateau of the vertebra above the segment and the lower plateau of the vertebra below the segment, Global lumbar lordosis (gLL); the angle between the upper plateau of L1 and the lower plateau of L5.

This study was approved by the Institutional Review Board where it was developed and following approval, was assigned number 0360/11.

The statistical tests were performed using the SPSS program (version 10.0, Chicago, IL) with alpha values equal to 0.05. The Student's t test, ANOVA, and Pearson correlation test were performed.

Figure 3. Example of measurements of the angulation of the lumbar spine (green lines) in the median sagittal cut. Values of the measurements of global lumbar lordosis (L1-L5) and segmental lumbar lordosis by level (L1-L2, L2-L3, L3-L4, L4-L5).

RESULTS

First, we studied the location of the bifurcation/confluence of the great vessels by lumbar vertebral levels. The results are shown in Table 1. The bifurcation of the abdominal aorta had a normal distribution varying from the vertebral body of L3 to the body of L5, with 52% of the cases splitting at the level of vertebral body L4 and with decreasing proportions at both the more cranial and caudal positions. The distribution of occurrences of the confluence of the common iliac veins was concentrated between L4 and L5.

Table 1. Lumbar level of the bifurcation/confluence of the great vessels.

	Abdominal aortic artery	Inferior vena cava
L2L3	0 (0%)	0 (0%)
L3	2 (2%)	0 (0%)
L3L4	30 (28%)	0 (0%)
L4	56 (52%)	28 (26%)
L4L5	19 (18%)	41 (38%)
L5	1 (1%)	39 (37%)
L5S1	0 (0%)	0 (0%)

Values are displayed as total occurrences (total percent).

The results of the distance between the vessels and the anterior aspect of the lumbar spine (intervertebral disc or vertebral body) are shown in Table 2. The results for the inferior vena cava show that the areolar space increases in the cranial direction ($p<0.001$), starting from a minimum average of 0.6 mm (54% of the cases with 0 mm) at the L4L5 level and reaching an average of 8.4 mm at the level of the L2 vertebral body. The values for the abdominal aorta show that it reaches its lowest average value (1.8 mm) at the level of the L3-L4 disc. At the L4-L5 and L4 levels, the right iliac artery was located in a superimposed position in front of the right common iliac vein in 58% and 88% of the cases, respectively. In contrast, the left iliac artery was only superimposed in front of the left common iliac vein in 9% of the cases at the L4-L5 level and in 6% of the cases at the L4 level. At the L3-L4 level and above, there was no overlapping of vessels. Table 2 shows one value per great vessels, and when there are two arteries or two veins, the average of the two values is displayed. The right and left vessel data at level L4-L5 follow (shown in millimeters, average ± standard deviation, 95 % confidence interval): LIA, 2.5 ± 2.4, 2.0-3.0; DIA, 4.8 ± 4.0, 4.0-5.6; LCIV, 0.4 ± 0.7, 0.2-0.6; RCIV, 0.8 ± 0.9, 0.6-0.4; and at level L4: LIA, 3.5 ± 1.8, 3.1-3.9; RIA, 6.9 ± 3.4, 6.1-7.7; LCIV, 0.8 ± 1.0, 0.4-1.2, RCIV, 2.3 ± 1.6, 1.5-3.1.

Table 2. Lumbar level of the bifurcation/confluence of the great vessels.

	Abdominal aortic artery		Inferior vena cava		P value
	average (sd)	95% CI	Average (sd)	95% CI	
L2	3.6 (2.1)	3.2 - 4.0	8.4 (3.9)	7.7 - 9.1	<0.001*
L2L3	2.2 (2.1)	1.8 - 2.6	4.2 (3.2)	3.6- 4.8	<0.001*
L3	3.4 (2.3)	3.0 - 3.8	3.8 (2.6)	3.3 - 4.3	0.350
L3L4	1.8 (1.9)	1.4 - 2.2	1.6 (1.8)	1.3 - 1.9	0.161
L4	4.6 (3.3)	4.0 - 5.2	2.1 (1.9)	1.7 - 2.5	<0.001*
L4L5	3.3 (3.3)	2.7 - 3.9	0.6 (0.9)	0.4 - 0.8	<0.001*

Values are shown in millimeters as average (standard deviation), and the lower and upper limits of the interval of the 95% confidence interval. *statistically significant

Among the lumbar discs, the areolar space for the abdominal aorta showed no tendency to either increase or decrease in the cranial direction ($p=0.135$). However, the areolar space of the cava became larger in the cranial direction ($p<0.001$), and the space in front of the discs was smaller than the space in front of the adjacent vertebral bodies ($p<0.001$).

The results of the maximum anteroposterior dimension of the discs and vertebrae are shown in Table 3. In the pairwise comparison of the dimension of the disc versus the adjacent vertebrae (ex. L4-L5 versus L4), it was possible to confirm that the discs are on average 11% larger than the adjacent vertebrae ($p=0.007$). The AP disc diameter values were higher than those of the adjacent vertebral bodies, reflecting a shorter distance and narrower areolar space between the vessels and the discs along the vertebral bodies ($p<0.001$; Table 3 and Figure 4).

Table 3. Anteroposterior dimension of the anterior spine.

	Average (sd)	95% CI
L2	35 (3)	35 - 36
L2L3	39 (5)	38 - 40
L3	37 (5)	36 - 38
L3L4	40 (4)	39 - 41
L4	36 (4)	35 - 37
L4L5	41 (4)	40 - 42

Values are shown in millimeters as average (standard deviation), and the lower and upper limits of the interval of the 95% confidence interval.

DISCUSSION

Due to the surgical significance of the great abdominal vessels in anterior access to the spine, our main objective was to study the extension and distribution of the areolar space between the great vessels and the lumbar spine, based on an evaluation of magnetic resonance imaging exams.

Traditionally, a procedure in the anterior lumbar spine by the lateral transpsoas approach relies on the integrity of the anterior longitudinal

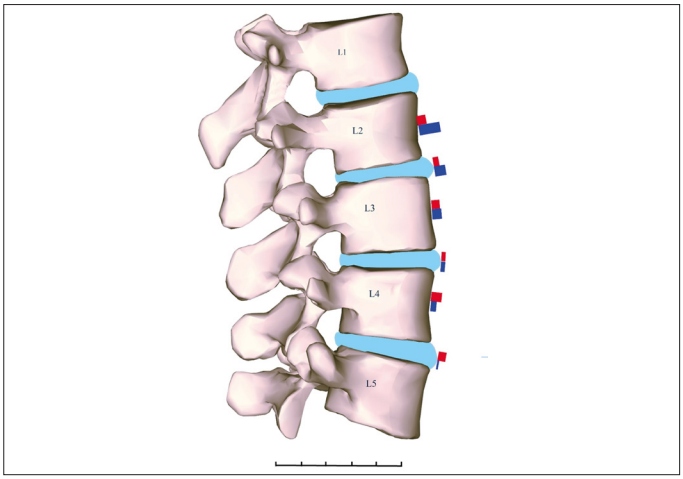

Figure 4. Schematic diagram of the areolar space between the spine and the great vessels. The bars represent the average values of the distance between the intervertebral disc/vertebra and the inferior vena cava/common iliac veins (blue bars) and between the intervertebral disc/vertebra and the abdominal aortic artery/iliac arteries (red bars). The dimensions of the intervertebral discs and of the vertebral bodies are represented in proportion to scale by average results obtained. The average lordosis values by segment were reproduced. The bar above the image represents the scale in centimeters.

ligament (ALL), which acts as a tension band and a barrier against migration of the interbody device. Thus, in general, manipulation of the region anterior to the spine where the abdominal vessels such as the vena cava and the aortic artery are located is not required. However, when the correction of a deformity in the sagittal plane is being considered, the complex anterior to the intervertebral disc, and the ALL, act as barriers to the stretching of the anterior spine and increase in lordosis. The first articles about this technique appeared in 2012 – a study in cadavers[21] that analyzed the power of correction in the sagittal plane, and a report of a case series[22] in which the technique was still being perfected. In 2014, Akbarnia et al.[5] published a complete description of the technique and a series of 17 cases (8 involving L4-L5) performed in two institutions. Although the identification of the plane between the ALL and the vascular structures was in use, it had not yet been analyzed or described in a form relevant to this surgical technique.

We observed that the anterior portion of the disc and the ALL are in close contact with the vessels. The difference between the areolar space in front of the discs and the vertebrae can be explained by the greater anteroposterior diameter of the discs and also anterior disc bulges, since the sample was made up of cases with mild to moderate degrees of degeneration. Because the vertebrae are smaller and a little farther away from the great vessels, they can be a safe point of reference for entrance into the plane between the spine and the vascular structures.

In relation to the areolar space, there are no studies in the literature, to our knowledge, in which the data was obtained in the same way. Studies that analyze the great vessels in relation to the spine tend to focus on the positioning of the vessels (for example, in relation to the plane in front of the disc,[14,15,18] the anteroposterior distance from the disc[8]), rather than on the smaller space in relation to the disc and the vertebra. Vaccaro and collaborators[8] described the position of the vessels in front of disc L4-L5, and the data on anteroposterior distance in that study are similar to those obtained in this study: LIA, 3.5mm; RIA, 5.1mm; LCIV, 0.3mm; RCIV, 0.3mm.

In general, our abdominal aorta bifurcation results are corroborated by earlier studies. Traditionally, the most common location for the separation of the aorta is the vertebral body of L4,[7,23–26] which occurs in up to 83% of cases, thus increasing the probability of dual arterial components in front of L4-L5. The inferior vena cava and the common iliac veins have a greater transversal diameter and are closer to the discs than the arteries. They form a wide vascular band, especially at the L4-L5 disc level, where the left common iliac vein crosses the midline to the right side.[26] Because veins have considerably thinner walls than arteries, it would be logical to assume that the veins are at greater risk for iatrogenic lesions, but the arteries can be inadvertently perforated during disc surgery.[1,27–29] The reference point for the confluence of the veins in the lumbar spine is lower than that of the arteries, occurring in the L4-L5 discal space or in the body of L5 in about 89% of cases, with fewer occurrences at the L4 level, varying between 17 and 26%.[7]

The results of this study, considered together with the literature, show reproducible data regarding the position of the bifurcation and the confluence of the great vessels, but it is worth bearing in mind that these points of reference can be altered by the presence of transitional vertebral segments.[23] The prevalence of lumbosacral variations (more or less than 5 vertebrae) is undefined, though the literature shows values that range from 3% to 30%.[30–32]

It should be noted that this study was conducted by analyzing exams in dorsal decubitus, a position in which the vascular structures tend to settle in a posterior direction against the spine. Therefore, the results obtained for the areolar space may be considered to be the lowest values dependent on decubitus. Deukmedjian et al.[10] studied the change in the position of the great vessels when moving from dorsal to lateral decubitus. They observe that the veins move more than the arteries in favor of gravity, and make recommendations for the positioning for discectomy at each level when dissection of the anterior portion of the fibrous ring and the ALL (a technique for segmental lordosis gain) are necessary. It should be noted that when this technique is performed, not only the vessel on the side of access, but also the one in the contralateral position, must be taken into account.

CONCLUSION

Although small, there is a space between the great vessels and the lumbar spine, this space being especially narrow in its distal portion. Therefore, via lateral access it is theoretically feasible to find the plane between these structures in order to protect the vessels and manipulate the complex in front of the disk and the ALL. Caution and thorough investigation of the anatomical position of the vessels are indispensable for the planning and verification of anatomical variations.

CONFLICTS OF INTEREST

Author LP has conflicts of interest with NuVasive, LLC: consultant, royalties, and shares. The other authors declare no conflicts of interest.

REFERENCES

1. Papadoulas S, Konstantinou D, Kourea HP, Kritikos N, Haftouras N, Tsolakis JA. Vascular injury complicating lumbar disc surgery. A systematic review. Eur J Vasc Endovasc Surg. 2002;24(3):189-95.
2. Billinghurst J, Akbarnia BA. Extreme lateral interbody fusion - XLIF. Current Orthopaedic Practice. 2009;20(3):238–51.
3. Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J. 2006;6(4):435-43.
4. Amaral R, Oliveira L, Coutinho T, Castro C, Coutinho E, Pimenta L. Opção minimamente invasiva lateral para artrodese intersomática tóraco-lombar. Coluna/Columna. 2011;10(3):239–43.
5. Akbarnia BA, Mundis GM Jr, Moazzaz P, Kabirian N, Bagheri R, Eastlack RK, Pawelek JB. Anterior column realignment (ACR) for focal kyphotic spinal deformity using a lateral transpsoas approach and ALL release. J Spinal Disord Tech. 2014;27(1):29-39.
6. Baghdadi YM, Larson AN, Dekutoski MB, Cui Q, Sebastian AS, Armitage BM, Nassr A. Sagittal balance and spinopelvic parameters after lateral lumbar interbody fusion for degenerative scoliosis: a case-control study. Spine (Phila Pa 1976). 2014;39(3):E166-73.

7. Kang BU, Lee SH, Jeon SH, Park JD, Maeng DH, Choi YG, Tsang YS. An evaluation of vascular anatomy for minilaparotomic anterior L4-5 procedures. J Neurosurg Spine. 2006;5(6):508-13.
8. Vaccaro AR, Kepler CK, Rihn JA, Suzuki H, Ratliff JK, Harrop JS, et al. Anatomical relationships of the anterior blood vessels to the lower lumbar intervertebral discs: analysis based on magnetic resonance imaging of patients in the prone position. J Bone Joint Surg Am. 2012;94(12):1088-94.
9. Guérin P, Obeid I, Gille O, Bourghli A, Luc S, Pointillart V, et al. Safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: a morphometric study. Surg Radiol Anat. 2011;33(8):665-71. 21384202.
10. Deukmedjian AR, Le TV, Dakwar E, Martinez CR, Uribe JS. Movement of abdominal structures on magnetic resonance imaging during positioning changes related to lateral lumbar spine surgery: a morphometric study: Clinical article. J Neurosurg Spine. 2012;16(6):615-23.
11. Delasotta LA, Radcliff K, Sonagli MA, Miller L. Aberrant iliac artery: far lateral lumbosacral surgical anatomy. Orthopedics. 2012;35(2):e294-7.
12. Postacchini R, Cinotti G, Postacchini F. Injury to major abdominal vessels during posterior lumbar interbody fusion. A case report and review of the literature. Spine J. 2013;13(1):e7-11.
13. Assina R, Majmundar NJ, Herschman Y, Heary RF. First report of major vascular injury due to lateral transpsoas approach leading to fatality. J Neurosurg Spine. 2014;21(5):794-8.
14. Kepler CK, Bogner EA, Herzog RJ, Huang RC. Anatomy of the psoas muscle and lumbar plexus with respect to the surgical approach for lateral transpsoas interbody fusion. Eur Spine J. 2011;20(4):550-6.
15. Uribe JS, Arredondo N, Dakwar E, Vale FL. Defining the safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: an anatomical study. J Neurosurg Spine. 2010;13(2):260-6.
16. Moro T, Kikuchi S, Konno S, Yaginuma H. An anatomic study of the lumbar plexus with respect to retroperitoneal endoscopic surgery. Spine (Phila Pa 1976). 2003;28(5):423-8.
17. Benglis DM, Vanni S, Levi AD. An anatomical study of the lumbosacral plexus as related to the minimally invasive transpsoas approach to the lumbar spine. J Neurosurg Spine. 2009;10(2):139-44.
18. Regev GJ, Chen L, Dhawan M, Lee YP, Garfin SR, Kim CW. Morphometric analysis of the ventral nerve roots and retroperitoneal vessels with respect to the minimally invasive lateral approach in normal and deformed spines. Spine (Phila Pa 1976). 2009;34(12):1330-5.
19. Smith WD, Youssef JA, Christian G, Serrano S, Hyde JA. Lumbarized sacrum as a relative contraindication for lateral transpsoas interbody fusion at L5-6. J Spinal Disord Tech. 2012;25(5):285-91.
20. Davis TT, Bae HW, Mok JM, Rasouli A, Delamarter RB. Lumbar plexus anatomy within the psoas muscle: implications for the transpsoas lateral approach to the L4-L5 disc. J Bone Joint Surg Am. 2011;93(16):1482-7.
21. Uribe JS, Smith DA, Dakwar E, Baaj AA, Mundis GM, Turner AW, et al. Lordosis restoration after anterior longitudinal ligament release and placement of lateral hyperlordotic interbody cages during the minimally invasive lateral transpsoas approach: a radiographic study in cadavers. J Neurosurg Spine. 2012;17(5):476-85.
22. Marchi L, Oliveira L, Amaral R, Castro C, Coutinho T, Coutinho E, et al. Anterior elongation as a minimally invasive alternative for sagittal imbalance-a case series. HSS J. 2012;8(2):122-7.
23. Chithriki M, Jaibaji M, Steele RD. The anatomical relationship of the aortic bifurcation to the lumbar vertebrae: a MRI study. Surg Radiol Anat. 2002;24(5):308-12.
24. Lakchayapakorn K, Siriprakarn Y. Anatomical variations of the position of the aortic bifurcation, iliocava junction and iliac veins in relation to the lumbar vertebra. J Med Assoc Thai. 2008;91(10):1564-70.
25. Lee CH, Seo BK, Choi YC, Shin HJ, Park JH, Jeon HJ, et al. Using MRI to evaluate anatomic significance of aortic bifurcation, right renal artery, and conus medullaris when locating lumbar vertebral segments. AJR Am J Roentgenol. 2004;182(5):1295-300.
26. Arslan M, Cömert A, Açar Hİ, Özdemir M, Elhan A, Tekdemir İ, et al. Neurovascular structures adjacent to the lumbar intervertebral discs: an anatomical study of their morphometry and relationships. J Neurosurg Spine. 2011;14(5):630-8.
27. Anda S, Aakhus S, Skaanes KO, Sande E, Schrader H. Anterior perforations in lumbar discectomies. A report of four cases of vascular complications and a CT study of the prevertebral lumbar anatomy. Spine (Phila Pa 1976). 1991;16(1):54-60.
28. Döşoğlu M, Iş M, Pehlivan M, Yildiz KH. Nightmare of lumbar disc surgery: iliac artery injury. Clin Neurol Neurosurg. 2006;108(2):174-7.
29. Prabhakar H, Bithal PK, Dash M, Chaturvedi A. Rupture of aorta and inferior vena cava during lumbar disc surgery. Acta Neurochir (Wien). 2005;147(3):327-9.
30. Castellvi AE, Goldstein LA, Chan DP. Lumbosacral transitional vertebrae and their relationship with lumbar extradural defects. Spine (Phila Pa 1976). 1984;9(5):493-5.
31. Hahn PY, Strobel JJ, Hahn FJ. Verification of lumbosacral segments on MR images: identification of transitional vertebrae. Radiology. 1992;182(2):580-1.
32. Elster AD. Bertolotti's syndrome revisited. Transitional vertebrae of the lumbar spine. Spine (Phila Pa 1976). 1989;14(12):1373-7.