# MRI-based Planning for an Extreme Lateral Interbody Fusion Procedure. Is It Safe? An MRI Study Describing the Statistical Distribution of Safe and Danger Zones

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## ABSTRACT

**Objective:** The objective of this study is to provide an anatomical description of the structures involved in the extreme lateral interbody fusion (XLIF) technique based on MRI images in the dorsal decubitus position. **Materials and Methods:** An observational, descriptive, and retrospective study of 200 patients treated at our institution was conducted using MRI images of the lumbosacral spine. The vena cava, aorta artery, and the width and height of the psoas muscle were measured in axial images to establish the safe and danger zones. **Results:** The final sample consisted of 164 patients, with a mean age of 50.4 for males and 50.6 for females. The abdominal aorta artery is located predominantly on the left side zone A on its path to the L3-L4 space. When it reaches the L4-L5 area, the iliac arteries bifurcate in 95.7% of the patients. The vena cava tends to be located on the right side, bifurcating at the L4-L5 level. **Conclusions:** Preoperative planning and safe zone delimitation are simple methods for determining the relative position of neural and vascular anatomical structures in relation to the surgical area. This technique can help spine surgeons prevent perioperative complications.

**Keywords:** XLIF; big blood vessels; lateral interbody fusion; nuclear magnetic resonance; psoas.

**Level of Evidence:** IV

## Planificación basada en imágenes de resonancia magnética para la cirugía de columna de acceso lateral. ¿Es un procedimiento seguro? Estudio descriptivo de distribución de grandes vasos y psoas

## RESUMEN

**Objetivo:** Realizar una descripción anatómica de las estructuras involucradas en el abordaje para la técnica de abordaje lateral (fusión intersomática lateral extrema) basada en imágenes de resonancia magnética en decúbito dorsal. **Materiales y Métodos:** Se llevó a cabo un estudio observacional, descriptivo, retrospectivo, de 200 pacientes evaluados con resonancia magnética de columna lumbosacra. Se tomaron mediciones en cortes axiales para determinar el posicionamiento de la vena cava, la arteria aorta, y el ancho y la altura del músculo psoas a fin de delimitar zonas de seguridad y de riesgo. **Resultados:** La muestra final incluyó a 164 pacientes con una edad media de 50.4 años en los hombres y 50.6 años en las mujeres. La arteria aorta abdominal en su recorrido hasta el espacio L3-L4 se ubica predominantemente del lado izquierdo en la zona A y, al llegar al espacio L4-L5, en el 95,7% de los pacientes, se observó la bifurcación de las arterias ilíacas. La vena cava mostró una tendencia de localización hacia el lado derecho y su bifurcación a nivel de L4-L5. **Conclusiones:** La planificación preoperatoria y la delimitación de la zona segura representan un método sencillo para evaluar la posición relativa de las estructuras anatómicas neurales y vasculares en relación con el área quirúrgica. Este método puede ayudar a los cirujanos de columna a prevenir complicaciones perioperatorias.

**Palabras clave:** Fusión intersomática lateral extrema; grandes vasos; resonancia magnética; psoas.

**Nivel de Evidencia:** IV

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# INTRODUCTION

Currently, spinal surgery is in transition between what is known as conventional surgery and minimally invasive spinal surgery. There are advantages and disadvantages to choosing one type of procedure over another, and it is clear that the path is leading us to become less aggressive and invasive, but we also cannot ignore the problems that various spinal centers around the world face, where they lack the necessary technology to perform this type of surgery safely.

The primary goal of spinal surgery is to relieve pain and correct any neurological deficits that may exist; what is sought with minimally invasive methods is a more ambitious goal that aims to improve quality of life through three important actions: preserve the anatomical vertebral structures, preserve the paravertebral musculature, and preserve the functionality of the segment. To achieve these objectives, three concepts emerged: a) minimal surgery; b) minimal access surgery; c) surgery to preserve mobility. These three concepts are covered by a single term: minimally invasive spine surgery.[1]

In 2006, Ozgur et al. described a new type of minimally invasive surgery called *extreme lateral interbody fusion* (XLIF).[2] The XLIF approach passes through the retroperitoneal space, separates the psoas major between the middle third and the anterior third, and reaches the lumbar intervertebral spaces. It is vital to choose the exact location at which it is entered through the psoas. This precision is necessary to reach the lumbar intervertebral space and avoid injury to the great vessels and nerves. If the puncture site is too anterior, the great vessels may be injured. However, if the puncture site is too posterior, lumbar nerve roots that have descended into the psoas muscle may be damaged.[3,4,5,6,7,8,9,10]. In addition, the width of the psoas at the entry point location also influences the safety of the procedure. If the psoas is very wide, the peritoneum is easily dissected, the retroperitoneal space is larger, surgery is safer, and the risk of peritoneal and abdominal viscera injury is reduced.[11] However, the distribution of the great abdominal vessels and psoas major muscles in each lumbar intervertebral space is inconsistent.[12,13,14,15]

There are few publications describing anatomy using magnetic resonance imaging (MRI),[12,16] and the samples are small.

Our objective was to describe the statistical distribution of important structures in order to propose safe zones and risk zones for the XLIF approach using a larger sample size than the rest of the published statistics.

# MATERIALS AND METHODS

## Study design

We developed a research protocol that was approved by the teaching and research committee of the Hospital Alemán de Buenos Aires, Argentina.

A descriptive, retrospective, observational analysis was performed. We included 200 patients over the age of 18 of both sexes who were treated at our institution and underwent an MRI for any reason between 2017 and 2020. The sample was selected randomly until 200 people were included. The exclusion criteria were: scoliosis (Cobb angle >10º), spondylolisthesis (grade >1 of the Meyerding classification), vertebral fracture and oncological lesions. The patients were contacted by telephone and their approval to be included in the study was requested.

Lumbar spine MRI was performed with Philips© 1.5 Tesla and General Electric© 3 Tesla equipment. Measurements were taken in axial sections of the segments L1-L2, L2-L3, L3-L4 and L4-L5, in which the position of the vena cava, the aorta artery, and the width and the height of the psoas in the area of each segment on both sides were determined. It was also recorded if the position of the psoas was too anterior (*Mickey Mouse* or *rising psoas sign*).[16]

The Moro[17] method was used, which divides the intervertebral space into six zones that go from anterior to posterior (Figures 1 and 2). The anterior aspect of the anterior margin of the vertebral body was defined as zone A; the posterior aspect of posterior margin, as zone P; zones I, II, III, IV were equally distributed between the anterior margin and the posterior margin, from anterior to posterior. The distribution of the great abdominal vessels in each zone of each lumbar intervertebral space was analyzed on the basis of the MR images. The width of the psoas in each zone of each lumbar intervertebral space on both sides was measured with the PACS Carestream© image analysis program. Psoas thickness was defined as the distance between the midpoints of the inner and outer margins of the psoas major in each zone (Figure 3).

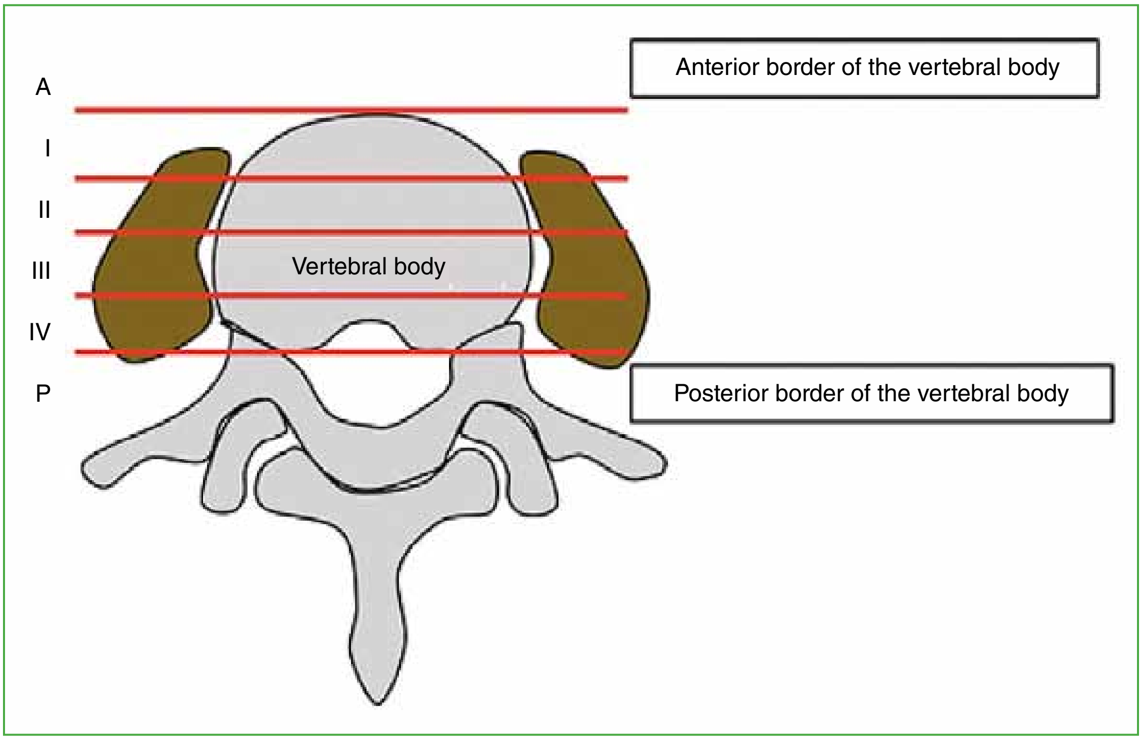


**Figure 1.** Moro's method describes six sections from anterior to posterior (A, I, II, III, IV and P).

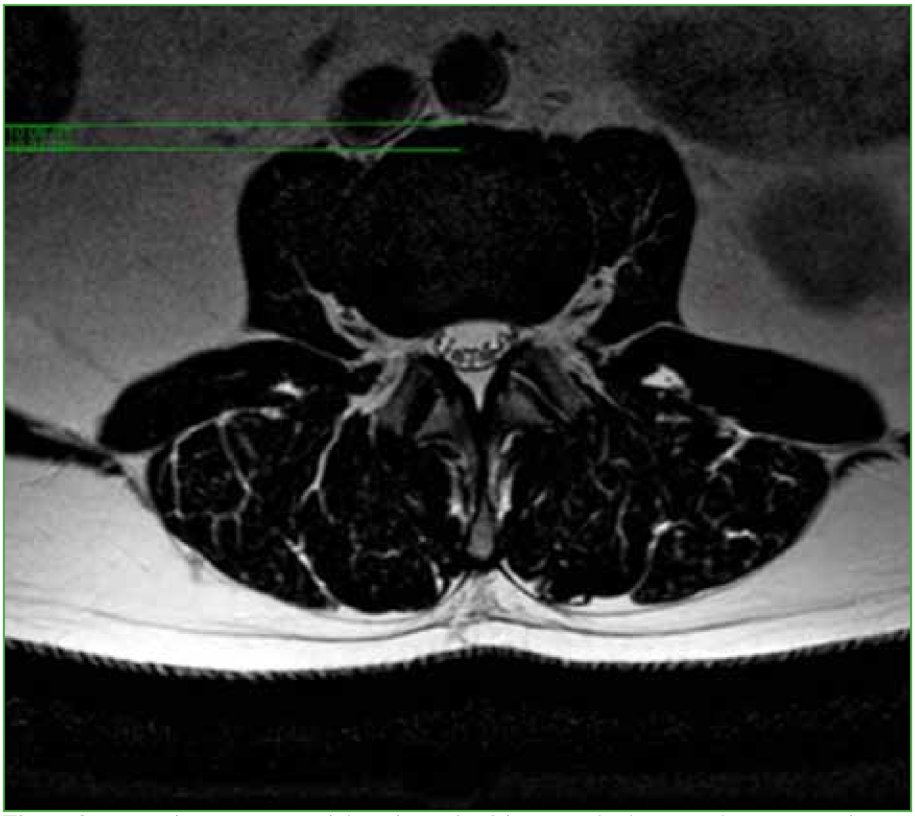

**Figure 2.** Magnetic resonance, axial section, L2-L3 intervertebral space. The vena cava is observed in position A and I (RA + RI).

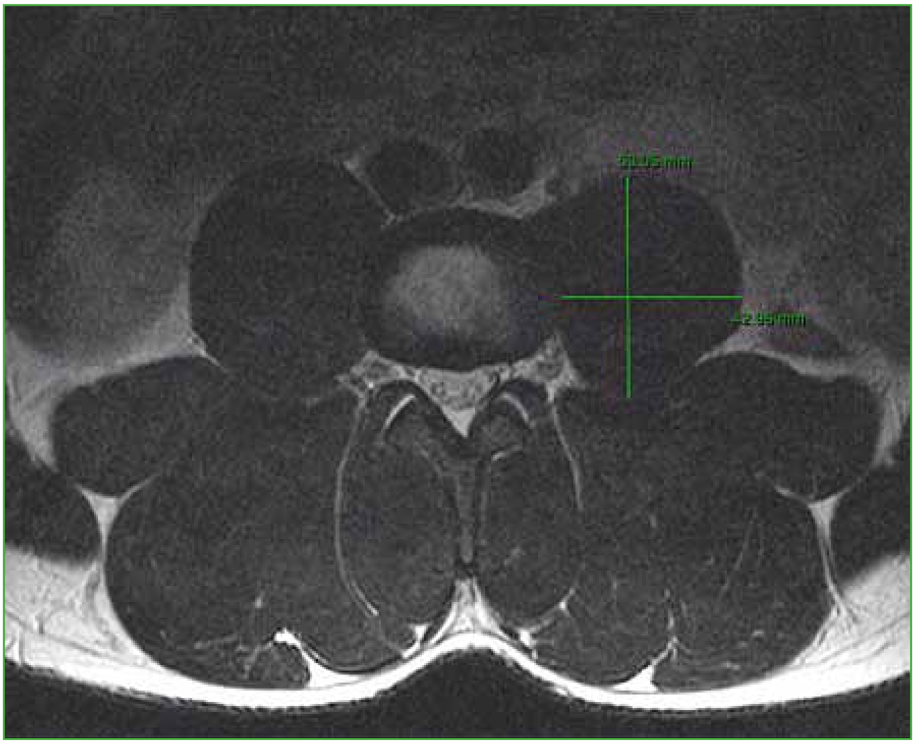

**Figure 3.** MRI, axial section, L3-L4 intervertebral space. Measurement of the length and width of the left psoas muscle is shown.

# RESULTS

200 MRI of the lumbar spine that were performed at our institution were analyzed. Thirty-six patients were excluded for meeting any of the exclusion criteria (tuberculosis, spondylolisthesis, scoliosis, and vertebral fracture). The final sample consisted of 164 patients, 87 women and 77 men. The mean age was 50.4 years for men and 50.6 years for women (Figure 4).

## Distribution of the abdominal aorta

The abdominal aorta artery in its route through the levels L1-L2, L2-L3 and L3-L4 is located predominantly on the left side, in zone A (n = 159, n = 157 and n = 137, respectively). Upon reaching L4-L5, 95.7% (n = 157) of the patients presented the bifurcation to the iliac arteries at that level (Figure 5).

## Inferior vena cava distribution

In its course through the L1-L2 level, the vena cava shows a 67.7% tendency to be located on the right side, in zone A (n = 111) and 32.3% on the right side, in zone A and zone I (n = 53). In L2-L3, 51.2% (n = 84) are found to the right, between zones A and I, while 48.8% (n = 80) are found on the right side, in zone A. In L3-L4, 68.3% (n = 112) were on the right, between zones A and I; 28.7% (n = 47) were on the right, in zone A; 1.8% (n = 3) had a bifurcation at this level; and 1.2% (n = 2) were on the right, in zone I. Finally, in L4-L5, 73.2% (n = 120) of patients had the bifurcation at that level; 21.3% (n = 35) had it on the right side, between zones A and I; in 2.4% of patients (n = 4), the vena cava was located on the right side in zone A; in 2.4% (n = 4), on the right side, between zone I and zone II; and in 0.6% (n = 1), on the right side, in zone I (Figure 6).

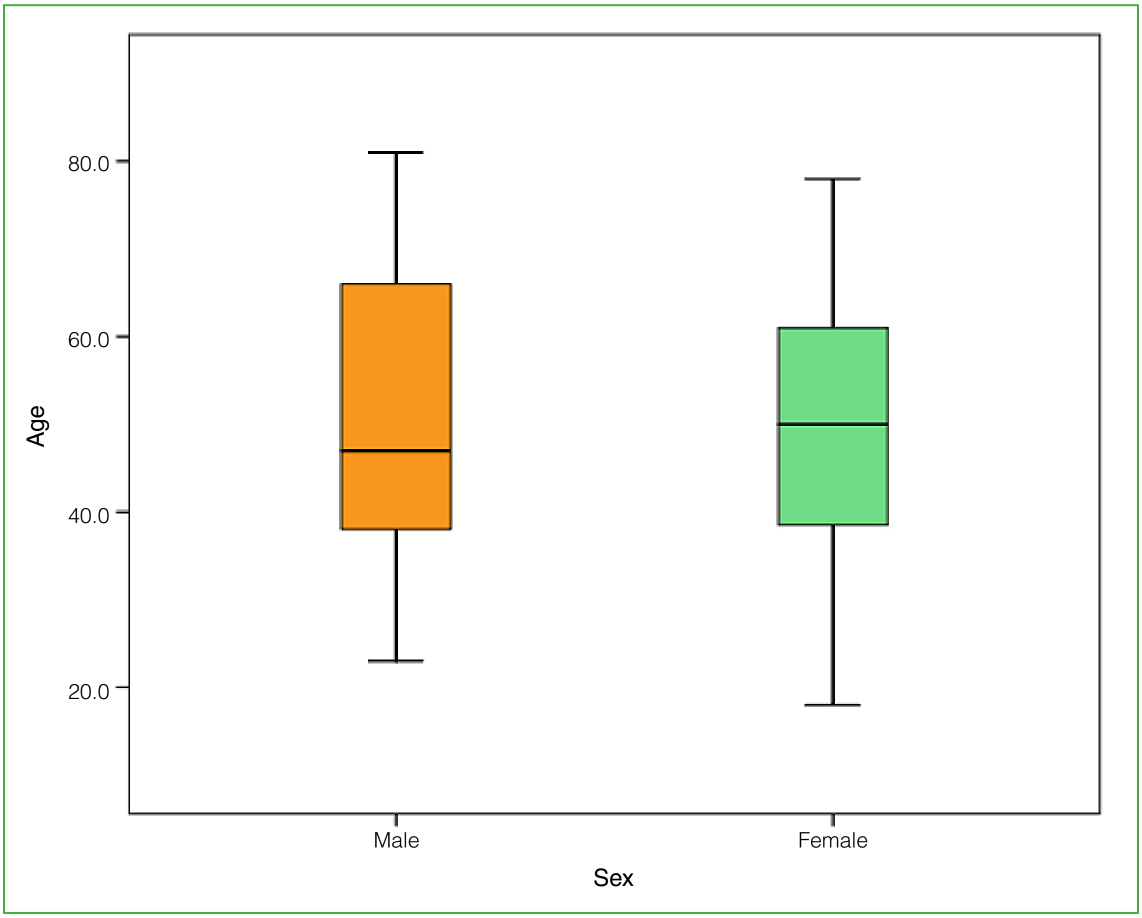


Figure 4. Representation of the sample according to sex and age.


Figure 5. Distribution of the abdominal aorta artery at each level and according to Moro's zones.

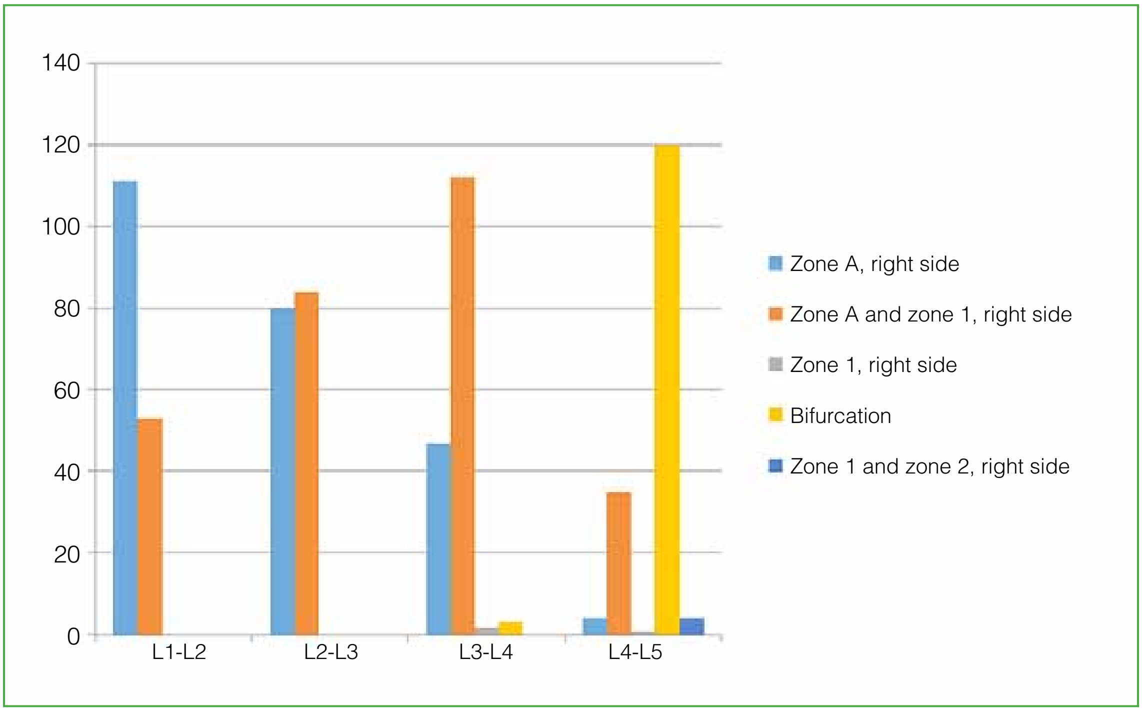


**Figure 6.** Distribution of the inferior vena cava at each level according to Moro's zones.

## Distribution of the right psoas major

The thickness of the right psoas muscle was evaluated at each level and in zones I, II, III, and IV. In L1-L2, women presented an average of 0.24 mm for zone I; 2.94 mm for zone II; 6.46 mm for zone III and 11.05 mm for zone IV. In L2-L3, a mean of 1.81 mm was observed for zone I; 9.87 mm for zone II; 13.85 mm for zone III and 17.04 mm for zone IV. In L3-L4, the means were: 6.44mm; 18.31mm; 22.98mm and 25.19mm, respectively. Finally, in L4-L5, the means were: 21.47mm; 30.81mm; 31.93 mm and 26.03 mm, respectively (Table 1).

**Table 1.** Female sex Mean, median, minimum and maximum values measured for the right psoas major muscle at each level (L1-L5) and in zones I, II, III and IV

| Female sex | | Right | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L1-L2 | | | | L2-L3 | | | | L3-L4 | | | | L4-L5 | | | |
| | | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV |
| n | Valid | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 |
| | Lost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | | 0.24 | 2.94 | 6.46 | 11.05 | 1.81 | 9.87 | 13.85 | 17.04 | 6.44 | 18.31 | 22.98 | 25.19 | 21.47 | 30.81 | 31.93 | 26.03 |
| Median | | 0.00 | 2.50 | 6.70 | 10.33 | 0.00 | 10.44 | 13.80 | 17.11 | 0.00 | 19.00 | 23.19 | 25.10 | 22.45 | 30.99 | 34.00 | 28.07 |
| Minimum | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.63 | 0.00 | 0.00 | 7.15 | 11.80 | 0.00 | 0.00 | 0.00 | 0.00 |
| Maximum | | 6.84 | 12.73 | 12.79 | 99.90 | 19.70 | 24.60 | 27.96 | 29.09 | 33.13 | 38.69 | 38.66 | 39.54 | 52.03 | 47.94 | 44.10 | 46.09 |

In L1-L2, men presented an average of 1.30 mm for zone I; 6.73 mm for zone II; 11.07 mm for zone III and 15.55 mm for zone IV. In L2-L3, a mean of 8.55 mm was observed for zone I; 18.27 mm for zone II; 21.63 mm for zone III and 24.37 mm for zone IV. In L3-L4, the means were: 21.22mm; 30.31mm; 32.70mm and 31.94mm, respectively. Finally, in L4-L5, the means were: 37.96mm; 41.16mm; 37.29 mm and 27.05 mm, respectively (Table 2).

**Table 2.** Male sex Mean, median, minimum and maximum values measured for the right psoas major muscle at each level (L1-L5) and in zones I, II, III and IV

| Male sex | | Right | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L1-L2 | | | | L2-L3 | | | | L3-L4 | | | | L4-L5 | | | |
| | | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV |
| n | Valid | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 |
| | Lost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | | 1.30 | 6.73 | 11.07 | 15.45 | 8.55 | 18.27 | 21.63 | 24.37 | 21.22 | 30.31 | 32.70 | 31.94 | 37.96 | 41.16 | 37.29 | 27.05 |
| Median | | 0.00 | 6.48 | 10.78 | 15.39 | 6.53 | 18.06 | 21.18 | 22.91 | 23.10 | 29.88 | 32.34 | 31.99 | 37.90 | 42.20 | 38.50 | 28.69 |
| Minimum | | 0.00 | 0.00 | 0.00 | 2.41 | 0.00 | 4.37 | 8.52 | 10.06 | 0.00 | 9.19 | 16.40 | 15.82 | 0.00 | 8.20 | 5.90 | 0.00 |
| Maximum | | 15.88 | 22.70 | 24.41 | 28.05 | 30.95 | 33.40 | 37.32 | 41.70 | 48.18 | 49.40 | 51.10 | 54.86 | 56.95 | 57.99 | 55.80 | 47.80 |

## Distribution of the left psoas major

The thickness of the left psoas muscle was evaluated at each level and in zones I, II, III, and IV. At the L1-L2 level, women presented an average of 0.41 mm for zone I; 4.12 mm for zone II; 7.32 mm for zone III and 10.51 mm for zone IV. At L2-L3, a mean of 2.67 mm was observed for zone I; 10.56 mm for zone II; 14.08 mm for zone III and 16.76 mm for zone IV. In L3-L4, the mean was 8.80 mm for zone I; 18.78 mm for zone II; 22.33 mm for zone III and 24.06 mm for zone IV. Finally, in L4-L5, the mean was 23.89 mm for zone I; 30.26 mm for zone II; 30.83 mm for zone III and 24.49 mm for zone IV (Table 3).

**Table 3.** Female sex Mean, median, minimum and maximum values measured for the left psoas major muscle at each level (L1-L5) and in zones I, II, III and IV

| Female sex | | Left | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L1-L2 | | | | L2-L3 | | | | L3-L4 | | | | L4-L5 | | | |
| | | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV |
| n | Valid | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 | 87 |
| | Lost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | | 0.41 | 4.12 | 7.32 | 10.51 | 2.67 | 10.56 | 14.08 | 16.76 | 8.80 | 18.78 | 22.33 | 24.06 | 23.89 | 30.26 | 30.83 | 24.29 |
| Median | | 0.00 | 4.17 | 7.10 | 10.66 | 0.00 | 10.90 | 13.90 | 15.95 | 6.69 | 17.40 | 22.40 | 23.51 | 24.90 | 30.92 | 32.20 | 26.40 |
| Minimum | | 0.00 | 0.00 | 0.00 | 2.10 | 0.00 | 0.00 | 0.00 | 8.10 | 0.00 | 0.00 | 11.19 | 8.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| Maximum | | 7.77 | 12.87 | 14.34 | 21.56 | 21.40 | 26.78 | 25.71 | 31.58 | 32.34 | 36.43 | 37.21 | 36.74 | 49.06 | 47.57 | 42.00 | 40.55 |

At the L1-L2 level, men presented an average of 1.87 mm for zone I; 8.31 mm for zone II; 12.18 mm for zone III and 15.92 mm for zone IV. In L2-L3, a mean of 9.57 mm was observed for zone I; 18.68 mm for zone II; 21.68 mm for zone III and 24.38 mm for zone IV. In L3-L4, the average was 22.62 mm for zone I; 30.56 mm for zone II; 32.26 mm for zone III and 30.77 mm for zone IV. Finally, in L4-L5, the mean was 39.24 mm for zone I; 40.94 mm for zone II; 36.59 mm for zone III and 25.65 mm for zone IV (Table 4).

**Table 4.** Male sex Mean, median, minimum and maximum values measured for the left psoas major muscle at each level (L1-L5) and in zones I, II, III and IV

| Male sex | | Left | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L1-L2 | | | | L2-L3 | | | | L3-L4 | | | | L4-L5 | | | |
| | | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV | Zone I | Zone II | Zone III | Zone IV |
| n | Válido | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 | 77 |
| | Perdidos | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | | 1.67 | 8.31 | 12.18 | 15.92 | 9.57 | 18.68 | 21.68 | 24.38 | 22.62 | 30.56 | 32.26 | 30.77 | 39.24 | 40.94 | 36.59 | 25.65 |
| Median | | 0.00 | 8.58 | 11.90 | 15.20 | 10.60 | 18.44 | 20.44 | 22.71 | 22.39 | 30.07 | 31.84 | 30.70 | 39.19 | 42.03 | 38.74 | 25.75 |
| Minimum | | 0.00 | 0.00 | 0.00 | 2.41 | 0.00 | 4.57 | 9.57 | 9.71 | 0.00 | 10.90 | 14.73 | 11.98 | 2.60 | 8.60 | 0.00 | 0.00 |
| Maximum | | 17.90 | 20.18 | 26.20 | 34.00 | 30.93 | 35.51 | 39.00 | 43.30 | 46.06 | 46.24 | 47.00 | 50.70 | 59.38 | 61.12 | 60.76 | 47.40 |

The results in both sexes are shown in Figure 7.

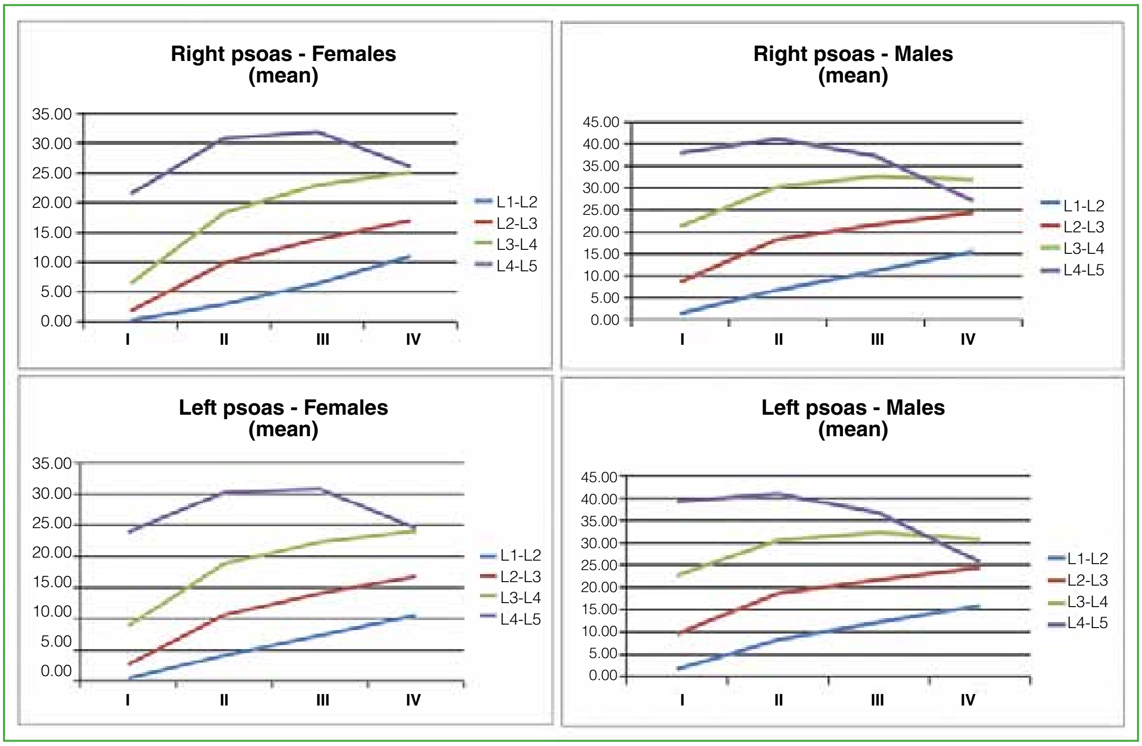


**Figure 7.** Distribution of the mean of the right and left psoas in both sexes according to Moro's zones.

### *Mickey Mouse sign or rising psoas sign*

8.5% of the patients evaluated had the rising psoas sign.

## DISCUSSION

The objective of this study was to describe, through MR images, the positioning of vital structures when performing extreme lateral interbody fusion (XLIF) and to correlate them with safety corridors in lateral approaches.

The lumbar plexus is made up of the anterior rami of L1-L4 in close relationship with the iliopsoas muscle. The safe zone for the lateral pathway is between these roots. There are multiple anatomical variants, both in relation to the morphology and location of said muscle, such as the rising psoas sign, as well as the lumbar plexus and its branches. The psoas major muscle is elevated lateral or anterior to the level of L4-L5, separating from the most posterior part of the disc space, leaving the lumbar plexus unprotected, which is a contraindication for lateral access surgery; therefore, proper pre-surgical planning is essential to avoid complications. This anatomical variant is called the Mickey Mouse sign or rising psoas sign.[18]

Moro published anatomical studies based on posterior peritoneal laparoscopic spinal surgery, the results of which revealed that the lumbar plexus is located in zone P, in the L1-L2 intervertebral space; in zone IV, in L2-L3; in zone III, in L3-L4 and L4-L5.[17] This is very useful for assessing which zones are least likely to cause neurological injury. In this way, for XLIF accesses in L1-L2 and L2-L3, it is recommended to carry them out in zones II or III. On the other hand, in L4-L5, it is recommended to separate the psoas major in zone II where the nerves ascend in the upper part of the muscle mass and thus reduce the risk of injury. At L3-L4, the plexus passes obliquely across the psoas major in a posterior to anterior direction. Because of this, those approaches at this level pose a greater risk of injury if performed in zone II.

Based on the measurements obtained in this study, we established safe zones depending on whether the approach was right or left. In right approaches, depending on the distribution of the vena cava, it is not injured in zones II/III/IV/P, at all lumbar levels. If this information is combined with the distribution of the plexus according to Moro, the safe zone in L1-L2 is located in zone II-IV; in L2-L3, in zone II-III; in L3-L4 and L4-L5, in zone II.

The thickness of the psoas in men is larger in zone IV in L1-L2 and L2-L3, whereas it is in zone III in L3-L4 and in zone III in L4-L5. In women, on the other hand, in L1-L2, L2-L3 and L3-L4, the thickness of the psoas is greater in zone IV, and, in L4-L5, in zone III.

Regarding the left approaches, according to the distribution of the aorta artery, the safe zones are located in zone II in L1-L2, L2-L3 and L3-L4, while, in L4-L5, they are in zone I. If this information is combined with the distribution of the plexus according to Moro, the safe zone in L1-L2 is located in zone II-IV; in L2-L3, in zone II-III; in L3-L4, in zone II and, in L4-L5, in zone I-II.

Based on the thickness of the psoas in men, we discovered that it is thickest in zone IV in L1-L2 and L2-L3, zone III in L3-L4, and zone I-II in L4-L5. In women, as on the right side, the thickness is greater in L1-L2, L2-L3 and L3-L4, in zone IV, and in L4-L5, in zone III.

The limitations of this study were that several of the included patients had already undergone spinal surgery, leading to a possible change in normal anatomy. On the other hand, the MRIs were searched in the database system of our center, since the MRIs were performed for some reason and not for the mere fact of collaborating with the study. On the other hand, there are variables that can modify the anatomy according to different situations in the same patient. Buckland et al. describe compensatory mechanisms, such as trunk flexion and increased thoracic kyphosis in patients with mild and moderate canal stenosis,[19] which were not taken into account when including patients in the study. Finally, because the patient is in lateral decubitus with the hips and knees flexed during the procedure, this causes changes in the vasculature as well as both psoas, which is a different anatomical relationship than the one that occurs with the patient in dorsal decubitus during the procedure.

## CONCLUSIONS

We can affirm that knowing the anatomy and the use of safe access routes for the placement of implants through lateral access is of the utmost importance, since most of the complications in these surgeries derive from this. The main challenge posed by this type of intervention is having direct visualization of the neurovascular structures, which can result in damage, which is why preoperative planning with the corresponding studies is essential, given the anatomical variations of the segment, in order to carry out a safe and correct procedure.

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Conflict of interest: Dr. Enrique Gobbi is a Nuvasive® spokesperson. The rest of the authors declare no conflicts of interest.

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