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The Surgical Vascular Anatomy of the Lower Lumbar Arteries and Its Implications in Minimally Invasive Spine Surgery: A Cadaveric Study

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ABSTRACT

Background: Minimally invasive lateral lumbar interbody fusion is a technique that has become increasingly popular for the treatment of degenerative lumbar spine disease; however, the pertinent surgical vascular anatomy has not been examined in detail. The goal of this study is to examine the anatomy of the lower lumbar and median sacral arteries, which are important determinants of these surgical outcomes.

Methods: This is an observational, experimental study based on cadaveric models, including 20 embalmed adult human cadavers. The following measurements were made: length of the lumbar and median sacral arteries, vertical distance between the third and fourth lumbar arteries and the superior end plate of the corresponding vertebrae, anterior vertebral body height, and intervertebral disc height.

Results: Our sample showcased considerable variability regarding vascular anatomy around the lower lumbar spine. In 10% of specimens, the abdominal aorta bifurcated at the level of the L3-L4 intervertebral disc, and 20% showed variations in vena cava origin. Regarding the lumbar arteries, in 10% of the sample, the fourth lumbar artery was absent on the right side, and 10% presented a fifth lumbar artery. The median sacral artery was present in all cadavers; however, in 15% of specimens, it originated from a common trunk that also gave rise to the fourth pair of lumbar arteries. Anterior vertebral body height was smaller in L3 comparing with L5 ($P = 0.003$), and there was a significant cephalocaudal increase in the anterior intervertebral disc height in the analyzed levels ($P < 0.001$). Bilaterally, the distance between the fourth lumbar arteries and the superior end plate of the L4 vertebral body was shorter than this distance at the L3 vertebral body ($P < 0.001$ and $P = 0.002$ on the right and left, respectively).

Conclusions and Clinical Relevance: These data may be useful in spine surgery planning and operative management. These anatomic variations should be identified beforehand to prevent difficulties during surgery and possible complications.

Level of Evidence: 4.

Lumbar Spine

Keywords: lumbosacral region, arterial anatomy, minimally invasive spine surgery

INTRODUCTION

The lower lumbar spine is a major site of spine disorders, with surgery frequently performed in this region. Anterior spinal interbody fusion is an effective treatment method for degenerative spine diseases and spinal deformities, and recent methodological and technical innovations in spine surgery have rendered the anterior spinal approach safe. More recently, other minimally invasive techniques in spine surgery, in particular the lateral approach to spinal fusion, through (lateral lumbar interbody fusion) or anterior (oblique lumbar interbody fusion) to the psoas muscle, are becoming widely performed.[1] The described advantages of these techniques include the avoidance of the need for a vascular or a general access surgeon and the reduction of the potential morbidities associated with the anterior open intra-abdominal procedure.[2]

Another point is the artery of Adamkiewicz, which is the only major arterial supply feeding the anterior spinal artery along the lower thoracic, lumbar, and sacral spinal cord. This vessel is clinically significant because injury to this vital artery can occur during a variety of procedures, most notably descending/thoracoabdominal aortic repairs. Injury to this artery can cause consequential neurologic damage manifesting as anterior spinal cord syndrome. This vessel usually originates from a left posterior intercostal or subcostal artery, a branch off the descending thoracic aorta, at approximately the levels of T9 to T12. However, the vessel may arise from either thoracic or abdominal aorta because its anatomical variability allows it to originate between T9 and L5.[3]

The lateral transpsoas approach can be performed with minimal disruption of spinal structures and muscles. Consequently, it offers many advantages, such as minimal blood loss, early mobilization, decreased operating time, generous discectomy, reduced postoperative pain, and shorter hospital stays.[4] However, as with any other type of surgical approach, some potential complications do exist and include injury to the bowel, lumbar plexus, and vasculature.[2] The injury of blood vessels, mainly at the level of aortic bifurcation, is one of the main complications of this approach, particularly when the spinal segments affected are the lower lumbar vertebrae because it requires careful dissection and mobilization of the blood vessels. In this situation, the incidence of vascular complications is reported to be up to 0.10% as revealed by a survey study of 13,004 patients whose surgery was performed by experienced surgeons.[5]

Although there are several studies that have examined the vascular anatomy of the lumbosacral region using cadavers, only a few have focused on the anatomical variations of the lower lumbar arteries or have examined whether these variations are gender related.[6–9] To address these important subjects, we have performed a detailed characterization of the vascular anatomy around the lower lumbar spine by cadaver dissection. Specifically, we inspected the anatomy of the right and left third and fourth lumbar arteries and the anatomy of the median sacral artery, and we recorded all noticeable anatomical variants around the lower lumbar spine, including the lumbosacral region. In addition, we performed a set of measurements to assess the relationship of these arteries to the pertinent intervertebral disc spaces.

MATERIALS AND METHODS

We designed an observational, experimental study based on cadaveric models. Twenty embalmed adult human cadavers (9 men and 11 women) of Caucasian (Portuguese) origin were subjected to routine dissection at our University Anatomy Department Unit. The cadavers derived from body donation with informed consent, written and signed by the donator (Portuguese Decreto-Lei n° 274/99).

The specimens were placed in a supine position and carefully dissected so as not to disturb the vascular and nervous anatomy related to the anterolateral region of the lumbar and sacral spine. None of the subjects presented a major deformity such as scoliosis or pathologic fracture.

Specifically, the anterior abdominal wall was reflected to access the contents of the abdominopelvic cavity. First, a midline incision was performed from the xiphoid process to the pubic symphysis, encircling the umbilicus. Then, a second incision was made from the xiphoid process along the costal margin to the midaxillary line. Finally, an inferior incision was done from the pubic symphysis to the anterior superior iliac spine, 1 cm below and parallel to the inguinal ligament. This incision was extended posteriorly below the iliac crest to the midaxillary line.[10] To access the contents of the retroperitoneum, the parietal peritoneum of the posterior abdominal wall was removed. Finally, the structures of the retroperitoneum were carefully dissected in order to preserve the normal anatomy of this region.

After dissection, the following direct metric measurements were made by 2 independent observers using a flexible surgical ruler (Figure): (1) length of the lumbar arteries from their origin in the abdominal aorta or in the common trunk to the medial border of the ipsilateral psoas major muscle; (2) length of the median sacral artery from its origin to the inferior border of the vertebral body of L5; (3) vertical distance between the third and fourth lumbar arteries at the medial border of the psoas major muscle and the superior end plate of the third (L3) and fourth (L4) lumbar vertebrae, respectively; (4) anterior vertebral body height, that is, the distance in the median plane between the superior and the inferior end plates of each vertebral body; (5) anterior intervertebral disc height, that is, the distance in the median plane between the superior and the inferior surfaces of each disc.

Statistical Analysis

Due to the small sample size, we chose to describe the various variables with the median and range and use nonparametric tests. To compare the anterior height of the intervertebral disc in the median plane among the 4 groups (L2-L3, L3-L4, L4-L5, and L5-S1), the Friedman paired sample test was used. Multiple comparisons for each pair of groups were performed with Wilcoxon signed ranks tests with Bonferroni adjustment. The same analysis was used to compare the anterior height of the vertebral body in the median plane among the 3 groups (L3, L4, and L5).

The Mann-Whitney test was used for gender comparisons (women and men), and the Wilcoxon signed

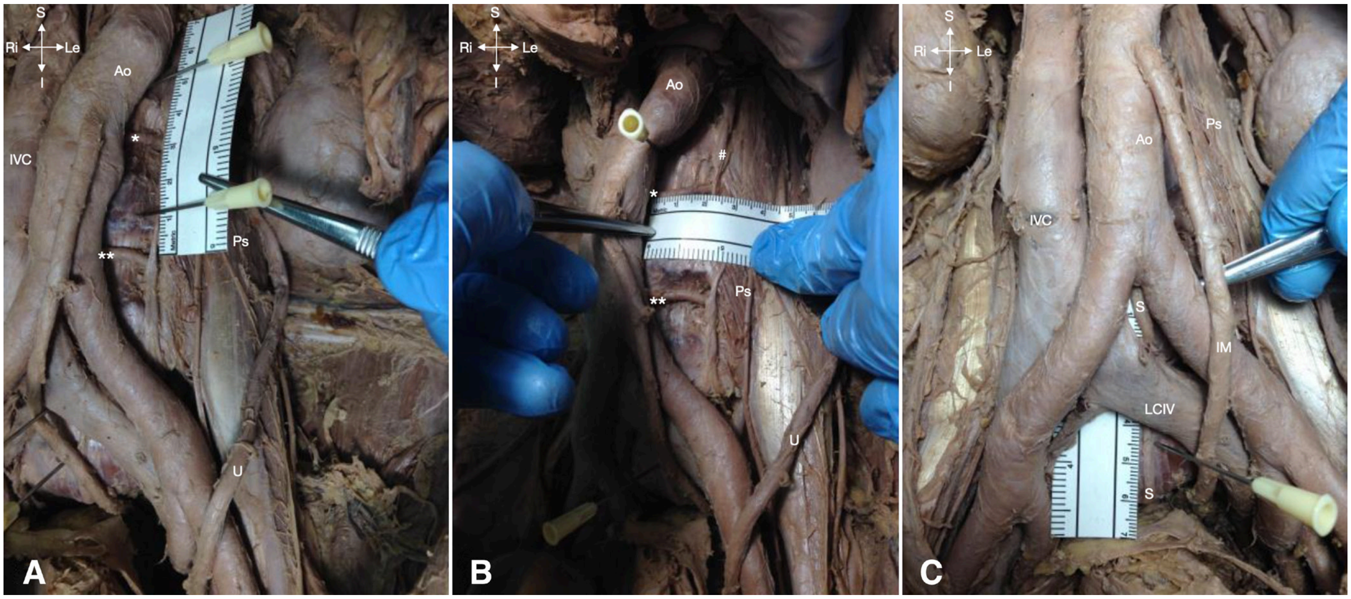

Figure. Dissection of the posterior abdominal wall and exemplification of how some of the measurements were obtained. (A) Distance between the left fourth lumbar artery and the superior and inferior border of the fourth lumbar vertebra, at the medial border of the psoas major muscle. (B) Length of the left third lumbar artery from the origin to the medial border of the psoas major muscle. (C) Length of the median sacral artery from the origin to the inferior border of the fifth lumbar vertebra. Ao, abdominal aorta; Ps, psoas major muscle; IVC, inferior vena cava; U, left ureter; *, third left lumbar artery; **, fourth left lumbar artery; #, left lumbar sympathetic trunk; S, median sacral artery; IM, inferior mesenteric artery; LCIV, left common iliac vein; I, inferior; S, superior; Ri, right side; Le, left side.

ranks test for comparisons between the left and right sides and between the third and fourth lumbar arteries.

Throughout the analysis, a significance level of 5% was considered.

RESULTS

We obtained a sample of 20 specimens. The age of the specimens ranged from 58 to 97 years, with a median age of 72 years. The age of the female specimens ranged from 58 to 97 years, with a median age of 74 years. The age of the male specimens ranged from 59 to 85 years, with a median age of 72 years. There was no statistically significant difference between women and men in regard to age ($P = 0.807$).

Anatomical Variations

According to standard anatomical textbooks, the abdominal aorta bifurcates into 2 common iliac arteries anterior to the L4 vertebral body or the L4-L5 intervertebral disc, slightly to the left of the midline.[11] In our study, the abdominal aorta bifurcated at higher level, that is, at the level of the L3-L4 intervertebral disc in 2 cadavers (1 woman and 1 man; 10% of the specimens). In addition, in another female cadaver (5% of the specimens), the abdominal aorta ended on the right side of the midline, anterior to the inferior vena cava.

The inferior vena cava is formed by the junction of the right and left common iliac veins anterior to L5 vertebral body, about 1 cm to the right of the midline.[11] In 1 female cadaver of our sample (5% of the specimens), this vein was formed at the midlevel of the L4 vertebral body, and the left common iliac vein crossed anterior to the L4 vertebral body. In addition, in 3 cadavers (2 men and 1 woman, 15% of the specimens), the inferior vena cava was formed anterior to the L4-L5 intervertebral disc.

Also according to anatomical textbooks, there are usually 4 lumbar arteries on each side, which arise from the posterolateral aspect of the abdominal aorta, opposite the lumbar vertebrae. A fifth, usually smaller, pair sometimes derives from the median sacral artery. This artery is a small branch that arises from the posterior aspect of the abdominal aorta a little above its bifurcation.[11] In our study, the third pair of lumbar arteries was present in all cadavers studied. However, the fourth lumbar artery was absent on the right side of 1 female cadaver and bilaterally in 1 male cadaver (10% of variability). In these cadavers, the caliber of the third pair of lumbar arteries was very large. Furthermore, in 2 of the female cadavers, the third pair of lumbar arteries originated from the abdominal aorta through a common trunk, and in 2 female and 2 male cadavers, the fourth pair of lumbar arteries also originated from the abdominal aorta through a common trunk.

Five lumbar arteries were present in 2 cadavers (1 woman and 1 man, 10% of the specimens). In the female cadaver, the arteries were present bilaterally, but in the male cadaver the artery was present only in the left side.

The median sacral artery was present in all cadavers. However, in 3 cadavers (2 woman and 1 man, 15% of the specimens), this artery originated from a trunk that also gave rise to the fourth pair of lumbar arteries.

Quantitative Data: Anterior Vertebral Body Height of L3, L4, and L5

The statistical analyses revealed a significant difference in the anterior vertebral body height in the analyzed levels ($P < 0.001$). In our sample, there was a tendency to the anterior vertebral body height increase from L3 to L4 (about 1 mm) and from L4 to L5 (about 1 mm). The statistical analysis revealed that the anterior vertebral body height was significantly different between L3 and L5 ($P = 0.003$), with the anterior vertebral body height of L3 being significantly smaller than the anterior vertebral body height of L5. However, no significant difference was obtained between the anterior vertebral body height of L3 and L4 ($P = 0.069$) or L4 and L5 ($P = 0.060$).

The anterior vertebral body height at all analyzed lumbar levels, was smaller in women than in men. However, there was no significant difference at L3 ($P = 0.154$) and L4 ($P = 0.785$) levels, and only at L5 level the difference was statistically significant ($P = 0.042$).

Quantitative Data: Anterior Intervertebral Disc Height (L2-L3, L3-L4, L4-L5, and L5-S1)

The statistical analyses revealed a significant difference in the anterior intervertebral disc height in the analyzed levels ($P < 0.001$). Indeed, there is a cephalocaudal increase in the anterior intervertebral disc height from L2-L3 to L5-S1 levels. The L2-L3 disc was significantly smaller than L3-L4 ($P = 0.006$), L4-L5 ($P < 0.001$), and L5-S1 ($P < 0.001$) discs. The L3-L4 disc was significantly smaller than L4-L5 ($P = 0.006$) and L5-S1 ($P < 0.001$) discs. Similarly, the L4-L5 disc was significantly smaller than the L5-S1 ($P < 0.001$) disc.

Although the anterior L4-L5 and L5-S1 intervertebral disc height was lower in women than in men, the statistical analyses revealed that gender had no significant effect on the anterior intervertebral disc height at any analyzed level (L2-L3, $P = 0.326$; L3-L4, $P = 0.636$; L4-L5, $P = 0.299$; L5-S1, $P = 0.236$).

Quantitative Data: Third and Fourth Lumbar Artery

The median distance between the origin of the third and of the fourth lumbar artery and the medial border of the ipsilateral psoas major muscle were significantly greater on the right than on the left side ($P < 0.001$ on both levels) (Table 1). No gender-related differences were found in these distances both on the right ($P = 0.566$ and $P = 0.179$ for the third and the fourth lumbar arteries, respectively) and on the left sides ($P = 0.909$ and $P = 0.679$ for the third and the fourth lumbar arteries, respectively). In addition, in this parameter, no significant differences were found between the right third and fourth lumbar arteries ($P = 0.358$) as well as between the left third and fourth lumbar arteries ($P = 0.467$). However, and despite the absence of statistically significant differences, on average, the third lumbar artery is, on both sides, longer in men than in women, but the fourth lumbar artery is, on both sides, longer in women than in men.

The vertical distance between the third lumbar artery and the upper border of the L3 vertebral body, measured at the medial border of the psoas major muscle, was not significantly different between the right and the left sides ($P = 0.075$). On both sides, there were no gender differences in this parameter ($P = 0.266$ and $P = 0.250$ for the right and the left sides, respectively).

No significant differences were found on the vertical distance between the fourth lumbar artery and the upper

Table 1. Lumbar arteries measurements in millimeters (mm).

Parameter Measured, mm	Overall		Women		Men	
	Left Median (Range)	Right Median (Range)	Left Median (Range)	Right Median (Range)	Left Median (Range)	Right Median (Range)
Length of the third lumbar artery from origin to the medial border of the psoas major muscle	22.00 (10–36)	31.00 (24–41)	22.00 (10–36)	30.00 (24–41)	24.00 (14–30)	32.00 (25–40)
Length of the fourth lumbar artery from origin to the medial border of the psoas major muscle	23.00 (11–35)	29.00 (24–40)	24.00 (11–35)	32.00 (26–35)	21.50 (18–30)	26.00 (24–40)
Distance between the third lumbar artery and the superior border of the third lumbar vertebrae	10.50 (6–14)	11.00 (3–19)	10.00 (6–14)	11.00 (5–15)	12.00 (6–13)	12.00 (3–19)
Distance between the fourth lumbar artery and the superior border of the fourth lumbar vertebrae	6.00 (2–12)	7.50 (−2 to 11)	4.00 (2–12)	6.00 (−2 to 11)	6,5 (4–11)	8.00 (0–11)

border of the L4 vertebral body, measured at the medial border of the psoas major muscle, between the right and the left sides ($P = 0.647$). On both sides, there were no differences between men and women in this parameter ($P = 0.532$ and $P = 0.182$ for the right and the left sides, respectively).

However, and despite the absence of statistically significant differences, it is important to highlight that the third and fourth arteries of the left side were slightly closer to the respective superior end plate than the arteries of the right side.

In addition, the distance between the right and left fourth lumbar arteries and the superior end plate of the L4 vertebral body was shorter than the distance between the right and left third lumbar arteries and the superior end plate of the L3 vertebral body, and the differences were all statistically significant ($P < 0.001$ and $P = 0.002$ for right and left sides, respectively). Analyzing the correlation between the distance of the third and fourth lumbar arteries of both sides, and the superior end plate of the respective vertebral body, on average the third lumbar artery crosses the middle third of the L3 vertebral body, and the fourth lumbar artery crosses the cranial third of the L4 vertebral body. Despite the absence of statistically significant differences regarding gender, it is important to highlight that the distance of the third and fourth lumbar arteries to the superior end plate of the respective vertebral body was, on average, smaller in women on both sides.

Regarding the 2 cadavers in which the fifth lumbar arteries were present (1 man unlilaterally and 1 woman bilaterally), the distance between the origin of the right lumbar arteries and the medial border of the ipsilateral psoas major muscle was 27 (woman) and 14 mm (man), and the distance between the origin of the left artery and the medial border of the psoas major muscle in the female cadaver was 23 mm.

Quantitative Data: Median Sacral Artery

The median sacral artery was present in all cadavers. The median distance between the origin of this artery and the inferior border of the body of the fifth lumbar vertebra did not differ between men and women ($P = 0.568$) (Table 2).

Table 2. Median distance between the origin of the median sacral artery and the upper border of the body of the fifth lumbar vertebra.

Parameter	Median (Range)	
	Woman	Man
Distance between the origin of the median sacral artery and the upper border of the body of the fifth lumbar vertebra, mm	53.00 (32–86)	60.00 (28–69)

DISCUSSION

Several studies[5,12–14] have reported that major and minor vascular injuries, iatrogenic artery pseudoaneurysms, and retroperitoneal hematomas are among the major complications of minimally invasive lateral access lumbar interbody fusion. Although relatively rare, understanding the regional vascular anatomy is imperative in order to prevent these potential hazardous outcomes.

Lumbar arteries provide blood supply to the spinal cord, and interruption of the blood flow in these arteries may be responsible for at least some cases of postoperative paraplegia in thoracoabdominal aneurysms surgery.[15]

Although abnormal variation in the abdominal vasculature is rare, there are a few cases reported in the literature, with Delasotta and collaborators[8] reporting a case in which the common iliac arteries branched at the level of L3-L4. Our sample also reported similar findings, with 2 cadavers (10% of specimens) showing the abdominal aorta bifurcating at the level of the L3-L4 intervertebral disc. We can argue that during an anterior approach such variation may present serious challenges to the surgeon, and therefore should be in mind.

Baniel and collaborators[16] found that the lumbar arteries followed a fairly regular pattern, with individual variations seen mainly in the total number of lumbar arteries arising from the aorta (range 2–4) rather than the course of the arteries. The most common pattern of the lumbar arteries (60% of the specimens) included 3 paired vessels exiting posteriorly at every third of the infrarenal aorta and coursing posterolaterally. Our observations showed that in 15% of the sample, the fourth lumbar artery had the same origin that of the median sacral artery. Besides that, in 10% of the sample, the fourth lumbar artery was absent on the right side, and 10% of specimens there was also present a fifth lumbar artery.

Sakai and collaborators[9] demonstrated that women had significant dorsal-migrated veins and arteries at L3-L4 and L4-L5 intervertebral level, and concluded that to avoid critical complications in minimally invasive lateral access lumbar interbody fusion, careful preoperative radiological evaluation of the major vessels and intraoperative care are important. In our sample, no statistically significant relationship was obtained regarding gender influence on the distance between the lumbar arteries and the vertebral bodies' end plates.

However, despite the absence of statistically significant differences regarding gender, it is important to highlight that the distance of the third and fourth lumbar arteries to the superior end plate of the respective vertebral body was, on average, smaller in women on both sides.

Furthermore, and despite the absence of statistically significant differences with laterality, it is important to highlight that the third and fourth arteries of the left side were slightly closer to the respective superior end plate than the arteries of the right side. This is of paramount importance if we take into account that most minimally invasive lateral access to the lumbar spine is done from the left side.

Orita et al[12] observed that there were generally low possibilities for the existence of segmental arteries below half of the vertebral height, where the surgeons can install fixation pins with ease and safety. However, segmental arteries can be involved in the surgical field of minimally invasive lateral access lumbar interbody fusion, especially in the lower lumbar spine, due to the L4 and L5 arteries, which can directly run across intervertebral discs. Besides that, L5 segmental arteries can also arise from the iliolumbar arteries and show an abnormal trajectory by nature.[6] Regarding our sample, the third lumbar arteries also remained on the middle third of the vertebral body. The median distance between the third lumbar artery and the upper border of the L3 vertebral body was significantly greater than the median distance between the fourth lumbar artery and the upper border of the L4 vertebral body. This is of great importance, as the L4-L5 disc is the most frequently surgically treated. Therefore, there is an additional need for extensive preoperative image planification and careful surgical dissection, not to section the fourth lumbar artery.

In the study report by Mustafa Alkadhim,[10] the course of the lumbar arteries was relatively regular, with the most common being the tendency for the lumbar pairs to bifurcate from a common trunk.[10] Beveridge and collaborates[17] also achieved a variation of 15% regarding lumbar arteries originating from a common trunk. In our study, we also observed that in 15% of the specimens, the fourth lumbar artery showed the same origin that of the median sacral artery.

Like previously reported,[18,19] in our study, the median sacral artery was also present in 100% of the specimens. However, in the study by Tribus et al,[18] the distance from the bifurcation to the top of the L5-S1 disc space averages 18 mm, but in our study the median distance was longer. Although it is important to identify and control the median sacral artery when the L5-S1 disc space is approached, the same care should be taken when approaching the L4-L5 space, since in some specimens of our sample this bifurcation is more proximal.

Our paper also has some limitations, the main one inherent to cadaveric experimental studies, being related to the changes in volume and trophicity of vessels and the intervertebral disc, with death and fixation techniques. We tried to minimize this by using mainly bony references. Other important limitation of our paper is the limited number of cadaveric specimens, which may have led to an underpower of this study results. Although higher-power anatomic studies are required to further define the surgical and functional anatomy of the lumbar region, this paper provides meaningful data in understanding the local relationships in our surgical workspace, beginning to define in more detail safe passages for minimally invasive spine surgery.

CONCLUSION

Our sample showcased considerable variability regarding vascular anatomy around the lower lumbar spine. In 10% of specimens, the abdominal aorta bifurcated at the level of the L3-L4 intervertebral disc, and 20% showed variations in vena cava origin. Regarding the lumbar arteries, in 10% of the sample, the fourth lumbar artery was absent on the right side, and 10% of specimens also present a fifth lumbar artery. The median sacral artery was present in all cadavers; however, in 15% of specimens, it originated from a common trunk that also gave rise to the fourth pair of lumbar arteries. Bilaterally, the distance between the fourth lumbar arteries and the superior end plate of the L4 vertebral body was shorter than this distance at the L3 vertebral body level ($P < 0.001$ on the right side and $P = 0.002$ on the left side).

Anterior vertebral body height also showed variations, being significantly smaller in L3 comparing with L5 ($P = 0.003$), and with a significant cephalocaudal increase in the anterior intervertebral disc height in the analyzed levels ($P < 0.001$).

Knowledge of vascular anatomy of the abdominal aorta is of great importance during surgical procedures, being of paramount importance the knowledge of the most common patterns and variations. Therefore, careful preoperative planning is critical in spine surgery.

Clinically, knowledge and proper management of the anatomical patterns described in this study may be pivotal in reducing the incidence of intraoperative damage to the lumbar vessels. With this paper, we hope to help better understand the variations in local anatomy, contributing to the better preparation of the surgeon. Extensive knowledge of these vessels' anatomic variations may help with surgical dissection and prompt location when needed, diminishing surgical time and bleeding.

These anatomic variations should be identified beforehand in order to prevent the difficulties during surgery and possible complications. These data may be useful in spine surgery planning and operative management, and also on the fields of vascular surgery, and forensic medicine.

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