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Research Article

L4-L5 Anatomy Classification System for Lateral Lumbar Interbody Fusion

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Introduction: Lateral Lumbar Interbody Fusion (LLIF), developed by Dr. Luiz Pimenta in 2006, allows access to the spinal column through the psoas major muscle. The technique has numerous advantages, including reduced damage to bone and muscular tissue, indirect decompression, larger implants, and the ability to correct lordosis. However, this technique also presents drawbacks, with the most notable being the risk of spinal pathologies due to indirect injury to the lumbar plexus, albeit with low rates of persistent injuries. Therefore, several groups have proposed classifications to aid in identifying patients at a higher risk of developing neurological deficits. The present work aims to propose a new classification system that relies on the simple observation of easily identifiable key structures to guide decision-making regarding lateral L4-L5 LLIF.

Methods: Patients aged 18 years or older who underwent preoperative magnetic resonance imaging (MRI) were included. This involved visits to the office between 2022 and 2023 until 50 quality images were obtained. Exclusions were made as follows: anatomical changes in the vertebral body or major psoas muscles that hindered the identification of key structures, or cases with poor-quality MRIs. Each anatomical configuration was categorized as type I, type II, or type III based on consensus among the three observers.

Results: This study included fifty anatomical sites. Seventy percent of the L4-L5 anatomies were classified as type I, 18% were type II, and 12% were type III. None of the type III L4-L5 anatomies were approached using a lateral technique.

Conclusion: The proposed classification offers an easy and simple method for assessing the feasibility of a lateral approach to L4-L5.

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Introduction

In 2006, Dr. Luiz Pimenta developed the lateral lumbar interbody fusion technique, providing access to the spinal column via the psoas major muscle. This method boasts several benefits, encompassing reduced damage to bone and muscle tissue, indirect decompression, the capacity for larger implants, and the potential for correcting lordosis [1][2][3].

Nevertheless, this technique comes with drawbacks, most notably the risk of psoas major muscle weakness and plexopathies due to indirect lumbar plexus injury, albeit with low rates of enduring harm [4][5][6].

The L4-L5 level proves to be especially challenging when utilizing the LLIF approach. This challenge arises due to the lumbar plexus's tendency to shift anteriorly at the lower levels of the spine [7][8]. Furthermore, in certain cases, the aorta, vena cava, or iliac veins/arteries may occupy the space between the major psoas muscle and vertebral body [9][10]. These combined factors constrict the safe working zone for LLIF at L4-L5, rendering it unfeasible in some instances. Additionally, factors like transitional anatomy or spinal deformities could alter the anticipated positioning of these vital structures in the L4-L5 segment. The effect of these factors further diminishes the safe working zone for LLIF at L4-L5, making it impractical in select cases. Moreover, elements such as transitional anatomy or spinal deformity could modify the expected location of these crucial structures in the L4-L5 segment [11][12].

Consequently, multiple groups have devised classifications to aid in identifying patients at a heightened risk of neurological deficits. Researchers across various classifications have frequently employed the Moro zone categorization to precisely determine the positions of key structures (psoas margin, lumbar plexus, and major vessels), and several groups have proposed classifications to assist in identifying patients at a higher risk of neurological deficits. Moro zone categorization has been used by researchers in most classifications to pinpoint the locations of key structures (psoas margin, lumbar plexus, and major vessels) [13][14][15].

Although prevailing classification systems for lateral procedure safety and accessibility are effective, they often involve numerous classification scenarios or necessitate the use of specific measurement tools that aren't universally available. Consequently, this study aims to introduce an innovative classification system based on straightforward identification of easily recognizable key structures. This system is designed to facilitate the decision-making process for lateral lumbar interbody fusion.

Methods

All participants signed a consent form allowing the use of their images in the study. The Ethics Research Committee approved this study.

Inclusion

Patients aged 18 years or older with magnetic resonance imaging (MRI) during the preoperative period, until 50 images of satisfactory quality were acquired.

Exclusion

Low-quality MRI scans or other factors that hinder the identification of key structures.

The assessed structures (Figure 1).

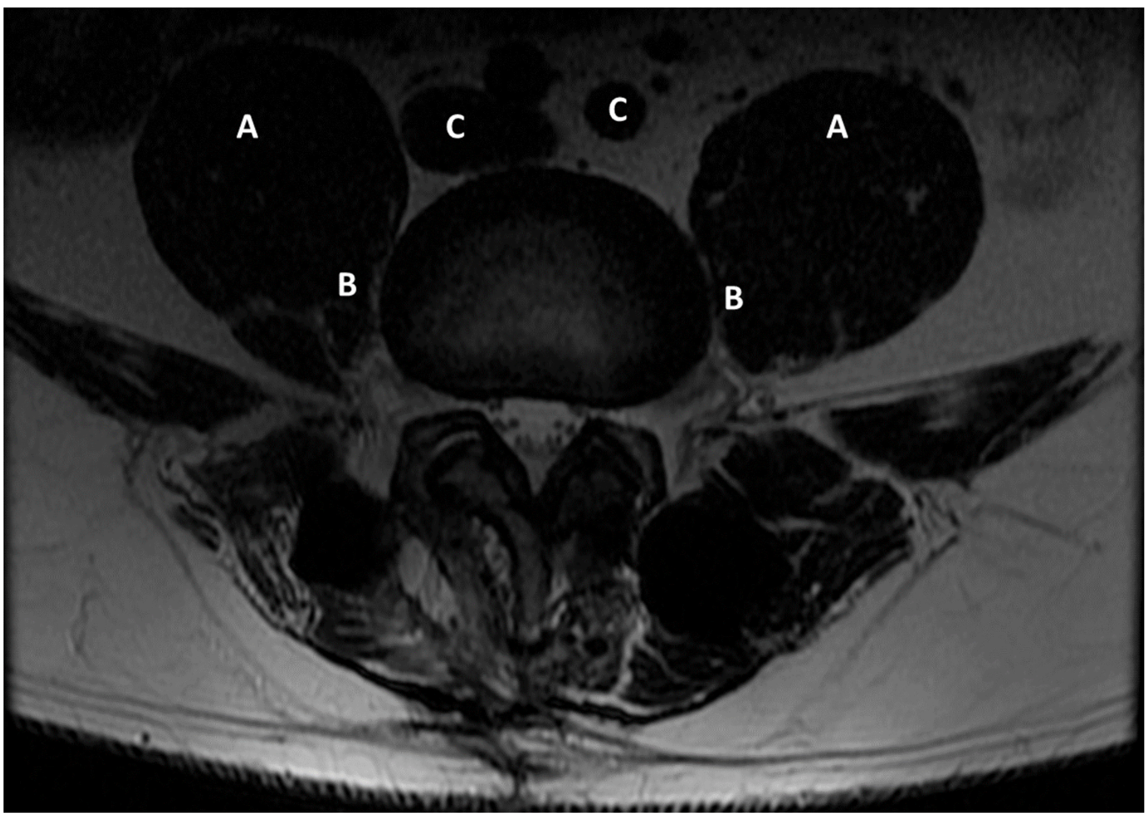

Figure 1. Visualization of the assessed structures. This includes the position of the Psoas major muscle in relation to the vertebral body (A), the plexus in relation to the vertebral body (B), and the major vessels in relation to the vertebral body and Psoas major muscle (C).

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The images were assessed by three experts (two senior clinical researchers and one spine surgeon), and the classification of each L4-L5 anatomy was established through consensus. The procedures performed on each patient remained undisclosed to the reviewers.

Each L4-L5 anatomy was categorized as type 1, type 2, or type 3, based on the agreement among the three measurements. Table 1 outlines the parameters employed to distinguish between the proposed types of L4-L5 anatomy, and Figure 2 illustrates the hypothetical positioning of the key structures in each L4-L5 anatomy type.

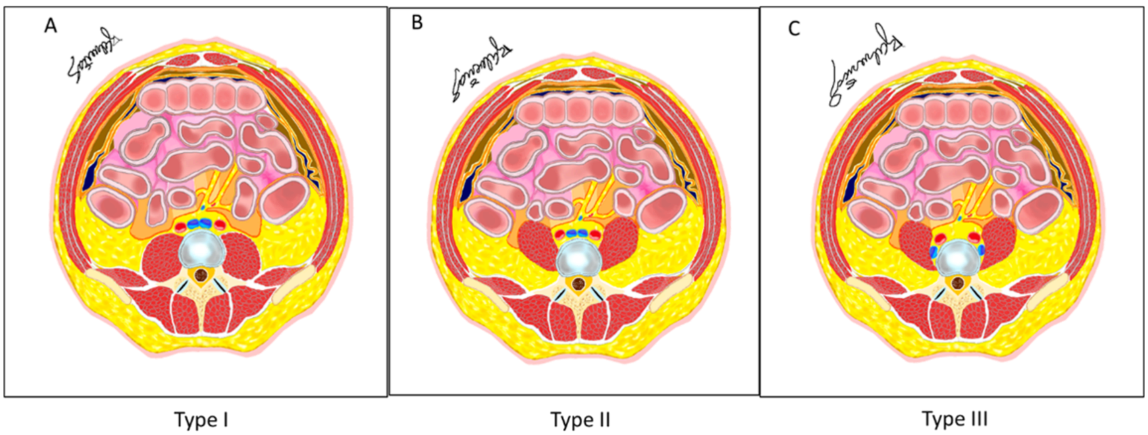

Figure 2. Illustration of each theoretical L4-L5 anatomy type. A: Type I, B: Type II, C: Type III.

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	Type I (Figure 2A)	Type II (Figure 2B)	Type III (Figure 2C)
Psoas muscle anterior margin	Posterior or marginal to the anterior margin of the vertebral body	Ahead of the anterior margin of the vertebral body. Usually elongated.	Ahead of the anterior margin of the vertebral body. Usually elongated with a larger anterior-to-posterior diameter than latero-lateral diameter.
Plexus position (when identifiable)	Posterior or marginal to the middle of the vertebral body	Posterior or marginal to the middle of the vertebral body	Anterior to the middle of the vertebral body
Vascular structures	Ahead of the vertebral body. Do not invade the psoas-vertebral space.	Ahead of the vertebral body. Do not invade the psoas-vertebral space.	More lateral in relation to the vertebral body. Invade the psoas-vertebral space.

Table 1.

Statistical Analysis

The images were analyzed using Radiant software, and the results were entered into a spreadsheet. R statistical software was used to perform exploratory analyses and summarize statistics [16].

Results

The study included fifty participants. According to Table 2, 70% of the L4-L5 anatomy was type I, 18% were type II, and 12% were type III.

	Type I	Type II	Type III
Number of psoas	35 (70%)	8 (18%)	6 (12%)

Table 2. Number of each type of L4-L5 anatomy in the sample

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Furthermore, when the surgery performed on each patient was examined, none of those with type 3 anatomy (7/7; six patients had ALIF L4-L5, and one underwent decompression at L4-L5) received a lateral approach.

Finally, the authors proposed a simple decision-making procedure based on the L4-L5 anatomy classification (Table 3).

	Type 1	**Type 2**	**Type 3**
LLIF Lateral	+	?	-
LLIF Prone	+	+	-
OLIF	+	?	-

Table 3. The authors' decision-making proposal is presented in a table.

+: It is safe to perform;

?: Exercise caution;

-: Do not perform.

Classification Examples

Figure 3 depicts a case of type 1 L4-L5 anatomy (Most common or expected L4-L5 Anatomy).

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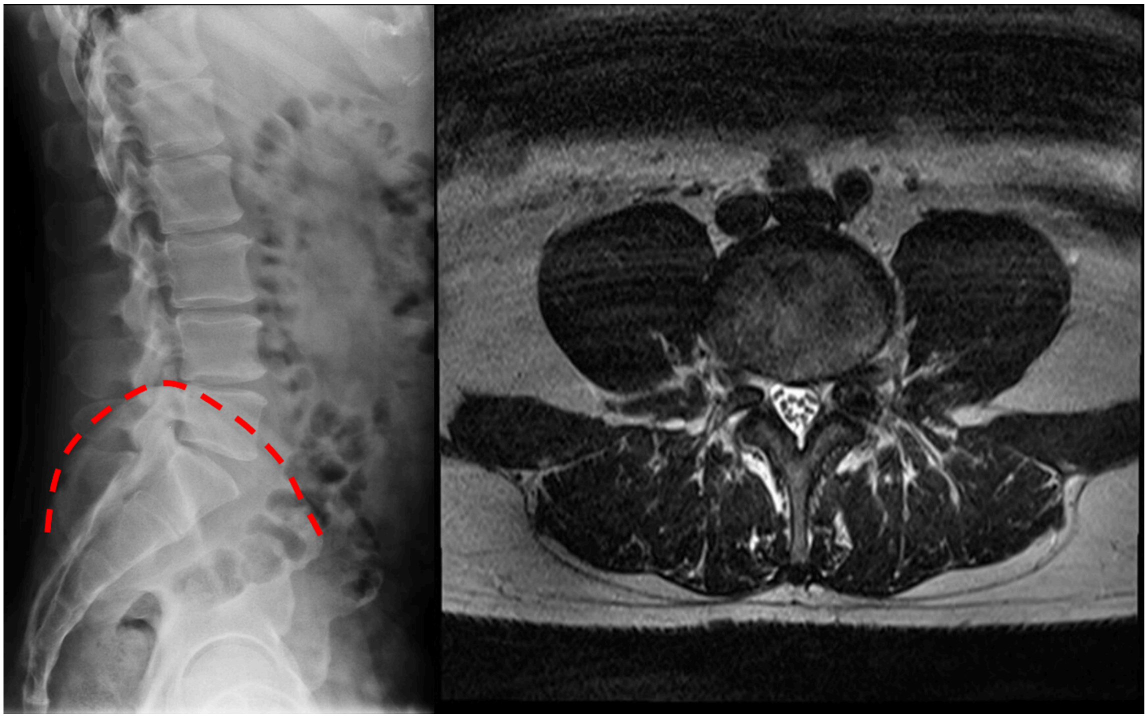

Figure 3. Type I L4-L5 anatomy. A: Lateral radiograph of the spinal column. The iliac crest is indicated by a red dotted line. B: Image of the axial plane of an MRI scan at the L4-L5 level.

Figure 4 depicts an example of type 2 L4-L5 anatomy, dubbed Deformity/External Forces L4-L5 Anatomy by the authors.

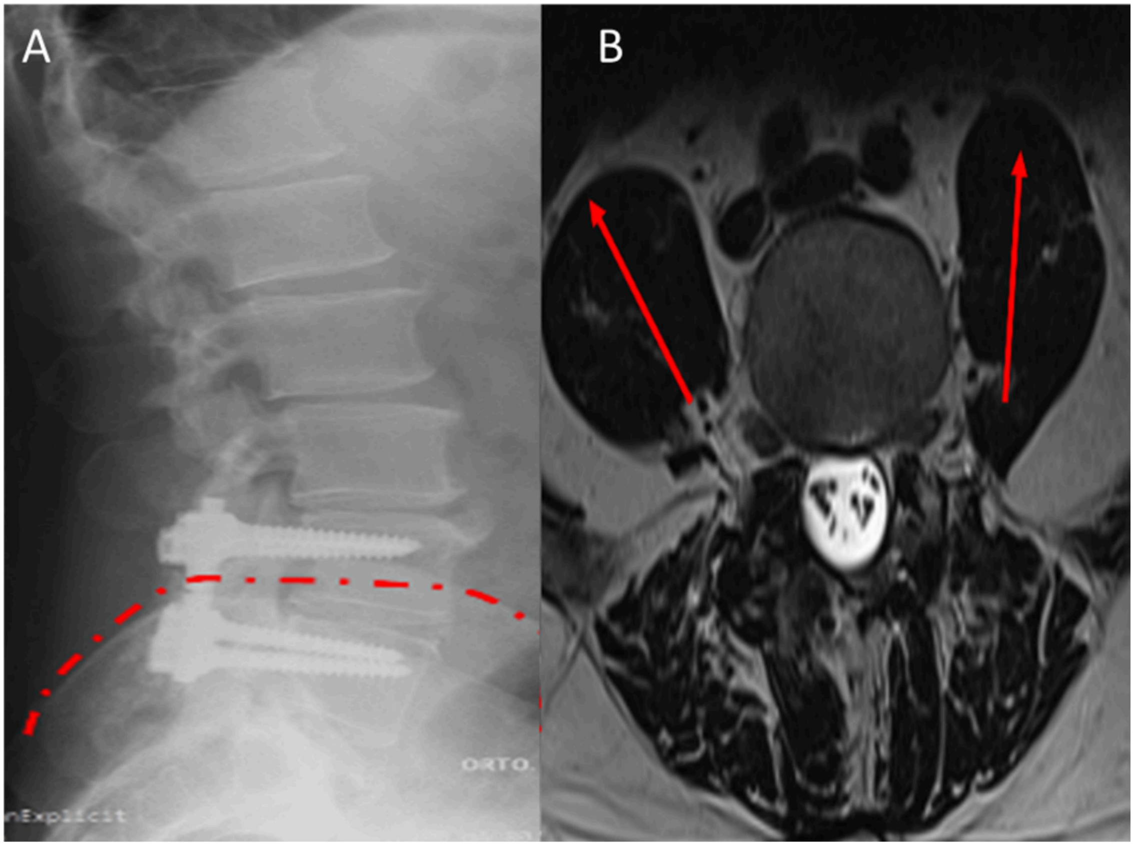

Figure 4. Type II L4-L5 anatomy. A: Lateral spinal column radiographs. The dotted red line represents the iliac crest. B: An MRI scan's axial plane at the L4-L5 level; red arrows denote external forces acting on the psoas muscle due to hypolordosis, as hypothesized by Ebata and colleagues (2018). The anatomy of type 1 L4-L5 is depicted in the figure. A: Lateral spinal column radiographs. The dotted red line represents the iliac crest. B: MRI axial plane at the L4-L5 level; red arrows denote external forces acting on the psoas muscle due to hypolordosis, as hypothesized by Ebata et al. (2018) [12].

Figure 5 depicts an example of type III L4-L5 anatomy, also known as transitional/severe deformity L4-L5 Anatomy.

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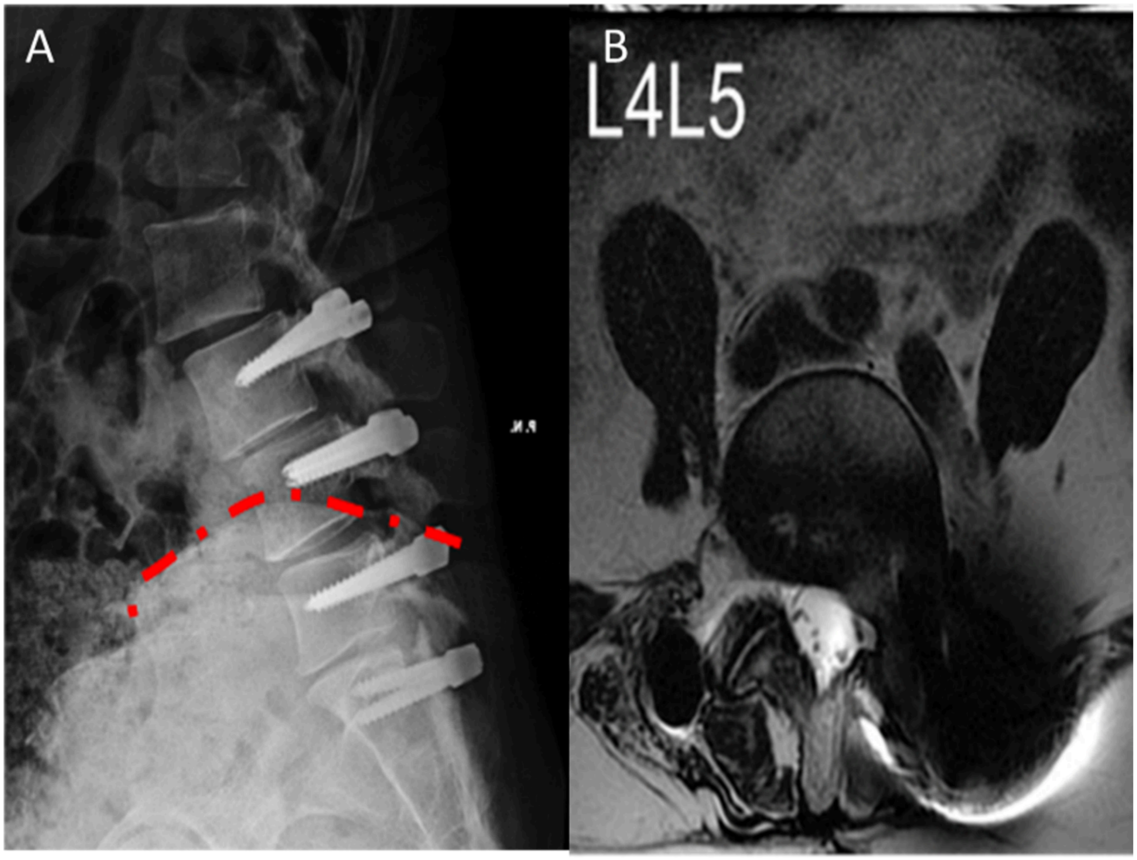

Figure 5. Visualization of type 3 L4-L5 anatomy. A: Lateral radiograph of the spinal column. The red dotted line represents the iliac crest. B: Axial plane MRI scan. The red circle indicates the exceedingly long psoas muscle, leading the lumbar plexus towards the anterior third of the vertebral body.

Discussion

Although LLIF is a safe and effective technique for treating spinal issues from T12-L1 to L4-L5, some surgeons express concerns about its use, particularly at L4-L5 [1][17]. Several authors have examined the specific anatomy of key structures to aid in identifying cases at risk of complications after LLIF at L4-L5.

Lumbar Plexus Position in L4-L5

Moro et al. (2003) were among the first to employ the Cartesian approach to determine the location of the lumbar plexus and its branches. They divided the vertebral body into six sections (I-IV), as well as

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posterior and anterior sections. The authors demonstrated that the plexus and femoral nerve were most commonly found at the L4-L5 level in the anterior zones (III or IV) [14].

Furthermore, Davis et al. (2011) showed in a cadaveric study that during the LLIF approach at L4-L5, dislocation of neural structures, primarily the femoral nerve, could occur in most cases. However, they observed that only three out of 18 cases had lumbar plexus branches that crossed beyond the midpoint of the disc [18].

Additionally, Uribe et al. (2010) proposed a safe working zone that included only the lumbar plexus neurological anatomy, demonstrating that the safe working zone (SWZ) shifted to a more anterior position at the L4-L5 level [19]. In a subsequent study, Kepler et al. (2011) revealed that one-third of the patients had a plexus located in a precarious area at L4-L5 [20].

Safe Working Zones

Although mapping the lumbar plexus position is a pivotal step in determining the safety of the LLIF approach, other factors such as the position of the psoas muscle or vascular structures can also play a role. To address these concerns, some authors have proposed the establishment of a safe working zone for the LLIF approach.

Regev et al., 2009, investigated the impact of the plexus position as well as the position of the major vessels on the safe working zones for the LLIF approach. The authors demonstrated that the SWZ was significantly reduced at L4-L5, with only 13% of the vertebral body considered free from the risk of nerve or vessel injuries [21]. Guerin et al. (2011) presented similar results to those of Regev et al. in a corresponding study. However, their findings indicated that the L4-L5 SWZ encompassed 37.5% of the vertebral body [8]. Recent studies evaluating the safe working zones for LLIF have shown that L4-L5 was accessible and instrumentable in approximately 70% of cases [22]. These results parallel those in this article, wherein only 17% of the psoas muscles were classified as type III/contraindicated for the LLIF technique.

Modifiable Factors Influencing L4-L5 Accessibility

Lumbar lordosis is an adaptable characteristic that may influence the safety of the approach to L4-L5. In a study published in 2017, Ebata et al. (2018) observed that patients with spinal abnormalities (severe loss of lumbar lordosis) exhibited a more anteriorized psoas muscle [12]. Tanida et al., 2020,

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reported a 'normalization' of the psoas position following treatment of spinal deformity, thus supporting the phenomenon reported by Ebata and colleagues [11].

Furthermore, recent studies have highlighted the intriguing benefits of LLIF in the prone position. According to Amaral et al., 2021, patients in the prone position exhibited a significant increase in lumbar lordosis (L1-S1) and L4-S1 lordosis, along with retraction of the anterior border of the psoas muscle [23]. Other research groups have found similar results, further confirming the effect of the prone position on increased lordosis and posterior shift of the psoas muscle [24][25]. Moreover, Tyler et al., 2020, demonstrated that the prone position, when combined with a coronal bending table, could not only enhance lordosis but also provide a wider window of coronal access [26].

However, the precise impact of prone positioning on the expansion of the L4-L5 disc's safe working zone remains uncertain, as certain studies noted substantial retraction of the femoral nerve in the prone decubitus position, while others reported no significant alteration [23][25][27].

Limitations

The present study is constrained by its small sample size and the lack of interobserver and intraobserver analyses. Additionally, relying solely on qualitative visual cues might lead to confusion, a compromise the authors consider worthwhile due to the simplicity with which their patients can be classified.

Conclusion

The proposed classification is a straightforward method for determining the feasibility of lateral lumbar interbody fusion surgery at L4-L5. It relies on the simple identification of anatomical markers that enable immediate visual recognition of the L4-L5 anatomical type.

The reliability of this categorization should be further investigated, as well as the connections between different classification patterns and surgical outcomes, such as the duration required for the transpsoas procedure or the occurrence of neurological deficits.

Disclosures

Dr. Rodrigo Amaral and Dr. Luiz Pimenta received consulting fees from ATEC. The other authors declare no conflicts of interest.

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Declarations

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