Transforaminal Endoscopic Approach to L5S1: Imaging Characterization of the Lower Lumbar Spine and Pelvis for Surgical Planning

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■ OBJECTIVE: **To determine and compare pelvic and lumbosacral reference parameters with computed tomography in patients with low back pain (LBP) and a control group of asymptomatic patients to provide quantification data and morphological correlations for L5S1 transforaminal endoscopic approach (L5S1TEA).**

■ METHODS: **We prospectively evaluated 100 patients with LBP and a control group of 100 individuals, with spinopelvic computed tomography. We measured lumbopelvic and L5S1 transforaminal approach parameters: maximum approach angle (maxAA) and minimum approach angle (minAA) and skin incision (maxSI and minSI), iliac crest (IC) projection at intersection point (ICPi), distance between the projected intersection of maxAA with the ilium (ICi) and the posterior limit of the IC (ΔICi-ICpost), and distance between ICi and spinous process (ΔICi-SP).**

■ RESULTS: **Females and ICPi were increased in the LBP group: maxAA: 48.38° ± 5.09°; minAA:32.5° ± 3.90°; maxSI: 11.39 ± 1.86 cm; and minSI: 8.30 ± 1.48 cm. Ilium intersection was increased in males; IC projection at the highest point (ICPh) was higher than ICPi; maxAA intersected the ilium in 28% and minAA in 1.5% of cases; ICi was positively correlated with facet angle, ICPh, and ICPi and negatively with ΔICi-SP.**

■ CONCLUSIONS: **Our results set preliminary reference values for L5S1TEA surgical planning. Besides higher ICPi, there were no differences between groups in measured parameters. Traditional IC height (ICPh) does not correspond to the point of intersection of the approach and is significantly higher than ICPi. ICi correlated to higher facet angle values, ICPh and ICPi grades, and lower ΔICi-SP. Potential conflict with the ilium is increased in the male population. IC is not impeditive of L5S1TEA in most cases.**

Key words
- Endoscopy
- High iliac crest
- L5S1
- Reference value
- Transforaminal

Abbreviations and Acronyms
ΔICi-ICpost: Distance between projected intersection of maximum approach angle with the ilium and posterior limit of the iliac crest
ΔICi-SP: Distance between projected intersection of maximum approach angle with the ilium and the spinous process
ΔICh-SP: Distance between the higher point of the iliac crest and the spinous process
CT: Computed tomography
IC: Iliac crest
ICi: Projected intersection of maximum approach angle with the ilium
ICh: Higher point of the iliac crest
ICPh: Iliac crest projection on lumbar spine at highest point
ICPi: Iliac crest projection at intersection point
ICpost: Posterior limit of the iliac crest
IELD: Interlaminar endoscopic lumbar discectomy
L5S1TEA: L5S1 transforaminal endoscopic approach
LBP: Low back pain
maxAA: Maximum approach angle
maxSI: Maximum skin incision
maxICi: Maximum ilium intersection
MD: Mean difference
minAA: Minimum approach angle
minSI: Minimum skin incision
PI: Pelvic incidence
SAP: Superior articular process
SP: Spinous process
TEA: Transforaminal endoscopic approach
TELD: Transforaminal endoscopic lumbar discectomy
trans-SAP: Transsuperior articular process

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Citation: World Neurosurg. (2023). https://doi.org/10.1016/j.wneu.2023.04.026

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

INTRODUCTION

Transforaminal endoscopic approach (TEA) to the spine is an established surgical technique with a wide range of applications, from addressing disc herniations and foraminal and lateral recess degenerative pathology to providing access to endoscopic-assisted lumbar interbody fusion techniques.[1]

In L5S1, TEA is known for its challenging singularity. The iliac crest (IC), foraminal and facet joints morphology, the L5 dorsal root ganglion anatomy, and the slope of the disk space have been pointed out as some of the limiting factors.[1-3] Some groups do not recommend L5S1 transforaminal endoscopic approach (L5S1TEA) due to impending pelvic structures, and others favor interlaminar endoscopic lumbar discectomy (IELD) due to a broader interlaminar space, decreased radiation time, and decreased operative time. However, despite the latter, transforaminal endoscopic lumbar discectomy (TELD) has shown similar clinical outcomes and safety compared with IELD[2,4-6] and was preferred for foraminal or extraforaminal disc hernitations[5] and also shoulder type, centrally located, and recurrent disc herniations.[4] In a randomized control trial comparing TELD and IELD in L5S1 under local anesthesia, TELD was favored due to less operative time, postoperative bed rest time, and complications, showing less intraoperative pain and a higher postoperative satisfaction rate.[7] Despite the reported increase in radiation and operative times in L5S1TEA, safety and reliable clinical outcomes have been established.[3,4,7,8] Increased development and availability of navigation technology applied to spine endoscopy will probably minimize the downside of radiation exposure and decrease operation time by allowing navigated placement of the initial guidewire.

Several studies reported on Kambin's triangle[9,10] dimensions, distance to exiting nerve root, and risk of injury. L5S1 has been shown to have the largest Kambin's triangle area among the lumbar levels, both in the superior articular process (SAP) retained and the SAP removed cohorts, even though a decrease in L4L5 and L5S1 Kambin's triangle area was shown to correlate with degenerative disc disease or spondylolisthesis, and therefore an extended foraminotomy or transsuperior articular process (trans-SAP) approach is advised in such cases.[11-13] On the other hand, despite being pointed out as a potential limiting factor, there is scarce literature on the morphology of the pelvis and IC and its correlation with L5S1 transforaminal trajectory. IC height is usually measured based on the sagittal projection of its highest point in the lumbar spine on standing lateral X-rays, which in most cases does not correspond to the effective point of intersection with the transforaminal access route.[3,14] Analysis of computed tomography (CT) images might allow a better understanding of the anatomy and more precise surgical planning.

We aim to determine and compare the pelvic and lumbosacral reference parameters with CT in patients with low back pain (LBP) and a control group of asymptomatic patients to provide quantification data and morphological correlations for L5S1TEA. In addition, we expect to contribute to the surgical planning and execution of TEA to L5S1 with relevant information.

MATERIAL AND METHODS

Study Population

This study was approved by the review board and the ethics committee of our academic and hospital institutions (nr.68/2019/CEFCM and CES/04/2020/ME). All participants provided written informed consent. Consecutive symptomatic patients undergoing lumbosacral CT for chronic LBP (minimum 6 months) and individuals undergoing pelvic CT for thoracic, abdominal, and urogenital indications were prospectively recruited from August 2021 to August 2022. Only participants over 18 years old were considered. Individuals with previous spine or pelvic fractures, spine tumors or infectious diseases, spine surgery, congenital spinopelvic anomalies, or hip replacement surgery were excluded. Individuals with CT signs of the previously mentioned exclusion criteria were also excluded. Participants with LBP or radiating pain to the lower limbs in the previous 6 months were excluded from the control group. Overall, 200 individuals were eligible for analysis (Figure 1).

CT Imaging

In either group, CT imaging was performed using a Somatom Force 192-slice and a Somatom Go TOP 64-slice CT scanners (Siemens, Erlangen, Germany). Patients' position was standardized in supine with knees extended and lower limbs parallel in neutral rotation.[15,16] The lower lumbar spine and pelvis were reconstructed from the superior end plate of L3 to the lesser trochanters, with a 1.5 mm thickness.

Measurements

Digital Imaging and Communications in Medicine images were uploaded for analysis using OsiriX MD (Pixmeo SARL©, Bern, Switzerland),[17] previously certified and validated for clinical use. For each subject, images were initially standardized and reformatted in coronal, axial, and sagittal planes to correct tilt, rotation, and pelvic obliquity, assuring the alignment of the femoral heads. Data collected in the axial plane were measured in a slice parallel and tangential to the S1 superior end plate in the sagittal plane.

Parameters were measured by 2 authors (J.M.S. and A.S.) and accessed for interobserver reliability. For intraobserver reliability, measurements were repeated at least 2 weeks apart.

Pelvic and lumbosacral anatomic parameters were measured as follows:

- 1) Pelvic incidence (PI), pelvic tilt, and sacral slope[18,19]; 2) iliac crest projection in the lumbar spine at its highest point (ICPh) (Figure 2); and 3) L5S1 facet angle (Figure 3).

The following L5S1 approach parameters were defined:

- 1) Maximum approach angle (maxAA), defined as the angle between the midline and a vector tangential to the lateral aspect of S1 superior articular process (SAP) crossing the center of the disc space; 2) minimum approach angle (minAA), defined as the angle between the midline and a vector tangential to the lateral aspect of S1 SAP crossing the most anterior point of the disc space; 3) working angle (workAA), defined as the angle between the

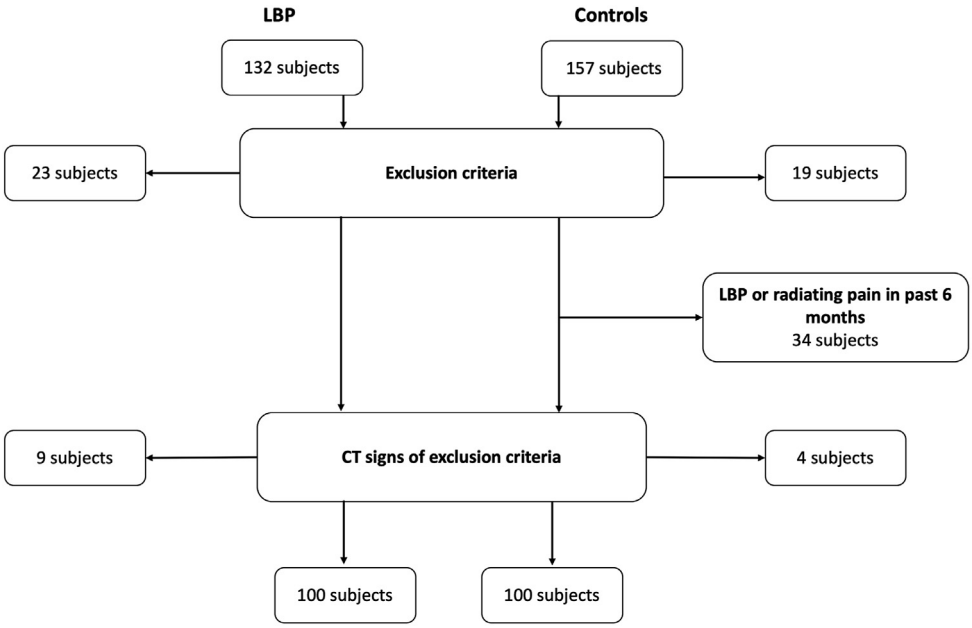

Figure 1. Flowchart of subjects from cohort inclusion to the final study population. LBP, low back pain.

tangential vectors of maxAA and minAA; 4) maximum skin incision and minimum skin incision (maxSI and minSI), defined as the distance between the midline and the point of intersection of maxAA and minAA tangential vectors with the skin (Figure 3); 5) Maximum ilium intersection (maxICi) and minimum ilium intersection (minICi), determined by the intersection or not of the ilium by the tangential vectors of maxAA and minAA, respectively; 6) iliac crest projection in the lumbar spine at its intersection point with the maxAA (ICPi); 7) distance between the intersection point to the posterior limit of the iliac crest (ΔICi-ICpost) (Figure 2); and 8) distance between the higher point of the iliac crest (ICh) and iliac crest intersection point with the maxAA (ICi) to the spinous process (SP) (ΔICh-SP and ΔICi-SP).

Lumbosacral anatomical parameters and L5S1 approach parameters were registered bilaterally.

Statistical Analysis

The means and standard deviation were calculated for the measured parameters. Paired *t* test was used to determine the statistical differences between continuous variables of both groups and subgroup analysis. The χ^2 test was used to determine statistical differences for nominal and ordinal variables. To evaluate the correlation between parameters, the Pearson correlation coefficient was used for continuous variables and Spearman for ordinal variables. Binary logistic regression was used to assess if the variables that correlated to maxICi independently modeled well the variation of this parameter.

When binary logistic regression for maxICi was used, a good model fit was obtained using the variables facet angle, ICPh, ICPi, and ΔICi-SP independently.

Statistical significance was set at P value < 0.05. Statistical analyses were performed using dedicated software (SPSS 26.0, IBM Corporation, Armonk, NY, USA).[20]

The interclass correlation coefficient was used to assess intraobserver and interobserver reliability of the measurements. Values of 0.75 to 0.90 and 0.90 to 1.00 were considered good and excellent, respectively.[21]

RESULTS

Baseline Characteristics

Images were obtained from 200 participants. The mean age was 56.21 ± 16.45 years (18–83) and 57.97 ± 14.46 years (19–87) for the LBP and control groups, respectively. The proportion of females was significantly increased in the LBP group (P value = 0.033) (Table 1). ICPi was significantly increased in the LBP group (P value = 0.005 and P value = 0.01 on the right and left sides, respectively).

There was no difference in the remaining lumbosacral anatomic parameters and L5S1 approach parameters measured between the LBP group and the control group.

Lumbosacral Anatomic Parameters

The overall mean PI was 48.58 ± 10.46° (24.41–83.50), the mean sacral slope was 36.35 ± 8.00° (13.47–58.64), and the mean pelvic tilt was 12.23 ± 6.03 (0.07–28.43).

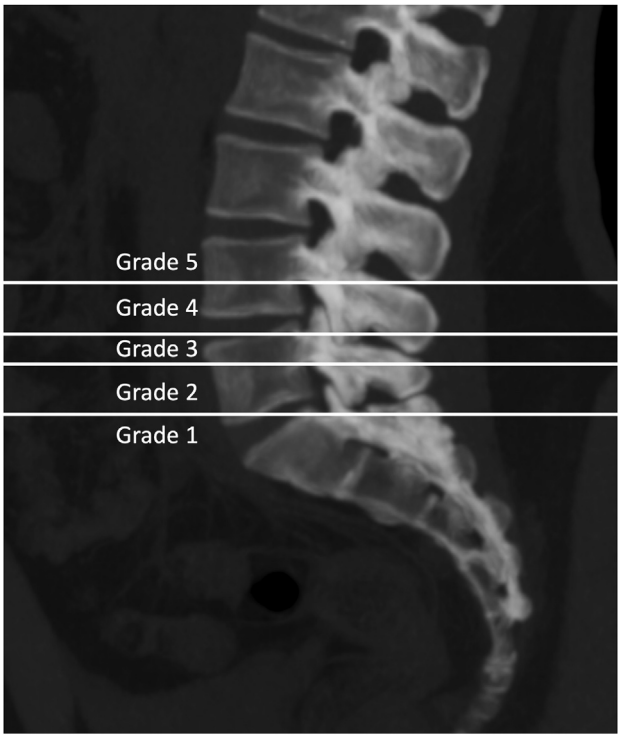

Figure 2. Iliac crest height grading system. Sagittal maximum intensity projection reconstruction of the lumbar spine image. Projection of the iliac crest at its highest point (ICPh) and its point of intersection (ICPi) with the maximum approach angle (maxAA) vector was graded from 1 to 5: grade 1, S1 pedicle or below; grade 2, L5S1 foramen; grade 3, L5 pedicle; grade 4, L4L5 foramen; and grade 5, L4 pedicle or above.

ICPh was above the L5 pedicle (grades 4 and 5) in 78% of the studied population. The mean L5S1 facet angle was 48.81 ± 9.60° (25.14–80.97).

L5S1 Approach Parameters

The overall measurements of L5S1 approach parameters are portrayed in Table 2.

The maxAA ranged from 27.79 to 63.20° (mean, 48.38 ± 5.09°), and the minAA ranged from 18.72 to 43.46° (mean, 32.50 ± 3.90°). The mean working angle was 16.24 ± 2.91° (9.08–30.73).

The mean maxSIP was 11.39 ± 1.86 cm (5.05–17.13), and the mean minSIP was 8.30 ± 1.48 cm (3.52–12.18). The mean difference (MD) between maxSIP and minSIP was 3.08 ± 0.81 cm (1.14–8.04).

The maxAA intersected the ilium in 112 projections, while the minAA intersected the ilium in 6 projections (N = 400). In most of the population with ICPh grade 5, there was an intersection of the ilium by the maxAA in 67.3%, and in the population with ICPh grade 4 and grade 3, it was observed in 29.0% and 3.5% of the projections, respectively (Table 3).

The distance of the maximum projected iliac crest intersection to the posterior edge of the iliac crest (ΔICi-ICpost) was 0.67 ± 0.39 (0–2.21) cm.

The mean ΔICh-SP and ΔICi-SP were 8.59 ± 0.86 cm (6.15–11.48) and 6.15 ± 0.74 cm (4.29–8.80), respectively. The MD between ΔICh-SP and ΔICi-SP was 2.44 ± 0.98 cm (0–5.89) Table 2.

The IC projection in the lumbar spine was significantly increased at its highest point compared to the projection at its intersection point (P value = 0.011).

Correlations

The correlations between the main lumbosacral anatomic measurements and L5S1 approach parameters are summarized in Table 4.

The PI had a positive correlation with ICPh and ICPi (P value < 0.001), a negative correlation with ΔICi-SP (P value = 0.034), and no correlation with facet angle, maxICi, or ΔICh-SP.

The maxICi had a positive correlation with facet angle, ICPh, and ICPi (P value < 0.001), a negative correlation with ΔICi-SP (P value < 0.001), and no correlation with PI nor ΔICh-SP.

The facet angle had a positive correlation with maxICi (P value < 0.001), a negative correlation with ΔICh-SP (P value = 0.014), and no correlation with PI, ICPh, ICPi, or ΔICi-SP.

When binary logistic regression for maxICi was used, a good model fit was obtained using the variables facet angle, ICPh, ICPi, and ΔICi-SP independently.

Subgroup Analysis

We performed subgroup analysis according to sex. In female participants, there was a significant increase in maxSI and minSI (P value = 0.012 and 0.014, respectively). In male participants, there was a significant increase in maxICi (P value < 0.001), minimum ilium intersection (P value = 0.008), ICPh (P value < 0.001), and ICPi (P value < 0.001).

We also performed subgroup analysis according to the ilium intersection occurring in the projection of both maxAA and minAA or only in the maxAA projected. The ICi-ICpost distance was significantly increased when the projection of the minAA intersected the ilium (MD, 0.62; 95% CI, 0.32, 0.93; P value < 0.001) (Table 5).

Reliability

Interobserver reliability was good in ΔICh-SP and ΔICi-SP. Intraobserver reliability was good in ΔICi-SP. Interobserver and intraobserver reliabilities were excellent in all other measurements.

DISCUSSION

Preoperative planning is critical for any surgical procedure. Identifying the main anatomic structures will determine the feasibility of a standard transforaminal endoscopic spine access or the need to perform an extended foraminoplasty, a trans-SAP approach, a transiliac approach, or to convert to another surgical option. Besides the exiting nerve root trajectory and foraminal morphology, other characteristics must be considered in L5S1 since the IC and lumbopelvic anatomy may cause additional constraints for a TEA.[1-3,8]

In the studied population, there was a higher frequency of females in the LBP group, which is in accordance with previous

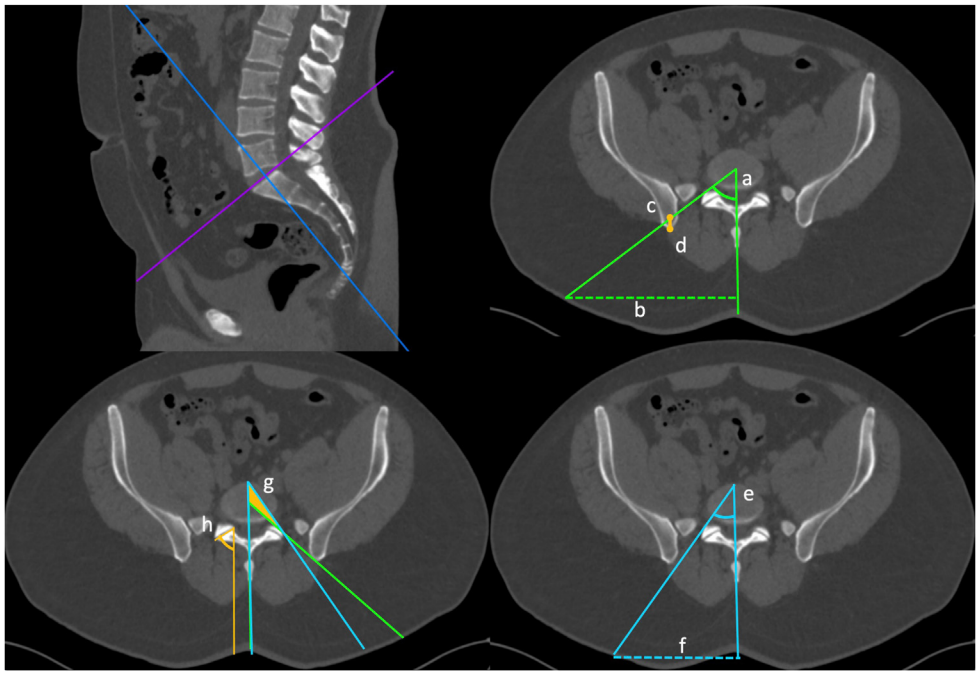

Figure 3. Sagittal and axial CT reformats. The axial plane used for measurements was defined as the slice parallel and tangential to the S1 superior end plate in the sagittal plane. All of the following parameters are measured in the same axial image. (**A**) Maximum approach angle (maxAA)—the angle between the midline and a vector tangential to the lateral aspect of S1 superior articular process (SAP) crossing the center of the disc space; (**B**) maximum skin incision (maxSI)—the distance between the midline and the point of intersection of maxAA vector with the skin; (**C**-**D**) distance between the intersection point of maxAA and the ilium (ICi) (**C**) to the posterior limit of the iliac crest (**D**) (ΔICi-ICpost); (**E**) minimum approach angle (minAA)—the angle between the midline and a vector tangential to the lateral aspect of S1 SAP crossing the most anterior point of the disc space; (**F**) minimum skin incision (minSI)—the distance between the midline and the point of intersection of minAA vector with the skin; (**G**) working angle—the angle between the tangential vectors of maxAA and minAA; and (**H**) L5S1 facet angle—angle defined by the line crossing the L5S1 facet joint space and the midline. CT, computed tomography.

reports.[22,23] Despite a significant increase of ICPi in the LBP group, there were no other significant differences in the morphometric and L5S1 approach parameters between both groups.

Subgroup analysis, according to sex, revealed that the level of the IC was significantly increased in males, either at its highest point or at the point of intersection with the ideal projected track to L5S1. Crossing of the ilium by both projected access tracks to the foramen was also more frequent in the male population, showing a higher chance of conflict for an L5S1 transforaminal approach than for female patients. On the other hand, despite females having a statistically significant increase in the distance between the skin incision and the midline, the MD was inferior to 0.5 cm, which may not be relevant in clinical practice. These findings correlate to the previously described anatomy of the pelvis and its distinction between male and female populations, namely the relatively longer and narrower pelvis of males, with higher reaching ICs.[24]

Table 1. Distribution by Sex in Low Back Pain Group and Control Group

	Female	Male	Total
LBP	61	39	100
Control group	46	54	100
Total	107	93	200

LBP, low back pain.

Our results show that the ICPh is significantly increased compared to the ICPi, even though both projections have a positive correlation. While the ICPh was above the L5 pedicle (grade 4 or 5) in 77.8% of the measurements, the ICPi was above the L5 pedicle in only 27.3%. Overall, 28% of the measures conflicted with the ilium when considering an ideal approach to the center of the disc space of L5S1. When considering the minAA, only 6 cases conflicted with the ilium, corresponding to 1.9% of cases with an ICPh grade 4 or 5. The mean distance to the posterior aspect of the

Table 2. L5S1 Approach Parameters

Parameter	Mean ± SD (Range)
maxAA	48.38 ± 5.09 (27.79—63.20)
minAA	32.50 ± 3.90 (18.72—43.46)
maxSI	11.39 ± 1.86 (5.05—17.13)
minSI	8.30 ± 1.48 (3.52—12.18)
ΔICh-SP	8.59 ± 0.86 (6.15—11.48)
ΔICi-SP	6.15 ± 0.74 (4.29—8.80)

maxAA, maximum approach angle; minAA, minimum approach angle; maxSI, maximum skin incision; minSI, minimum skin incision; ΔICh-SP, distance between the higher point of the iliac crest (ICh) and the spinous process (SP); ΔICi-SP, iliac crest intersection point with the maxAA (ICi) to the spinous process (SP); SD, standard deviation.

IC of the maxAA was 0.64 cm when only the ideal track crossed the ilium. In comparison, the mean distance increased to 1.26 cm in cases where both maxAA and minAA crossed the ilium. These findings suggest that almost one third of the cases could conflict with the IC considering the defined ideal transforaminal track to the disc space. However, only in a small percentage (1.5%) of all cases was it impossible to determine a trajectory that allowed transforaminal access aiming at the most anterior end of the disc space. Considering that the lumbosacral junction has some residual plasticity, it seems reasonable that the mean distance to the posterior end of the IC can be overcome in most cases when only the maxAA crosses the IC. Also, in most cases, an extended foraminotomy or a trans-SAP approach will probably allow to overcome the limitations that the IC might impose on an L5S1TEA.[11-13] Ultimately, in the residual cases where an L5S1TEA is not feasible, other alternatives can be used, namely, a transiliac transforaminal approach, an ipsilateral interlaminar approach, a contralateral interlaminar approach, or a complete facetectomy with supplemental fixation, depending on the specificity of each case and the surgeons' discretion. The presented results clearly demonstrate that current standing X-ray grading systems are unsuited to measure the IC height where it actually could interfere with an L5S1TEA.[3,8]

Besides a higher frequency in males, the intersection of the ilium by the maxAA correlated with higher facet angles, ICPh, and ICPi grades and a lower ΔICi-SP. These anatomic features seem to influence the possibility of IC constraints and should be considered in preoperative planning. PI also had a positive correlation with ICPh and ICPi and a negative correlation with the ΔICi-SP.

Based on the studied population, the ideal mean approach to L5S1 is around 48° in the axial plane, with a mean working angle of 16°. Angulation of endoscopic cameras furthers the field of vision and action with an actual reach beyond the mentioned working angle. This allows addressing foraminal and lateral recess pathology in most cases.

The mean distance of the skin incision to the midline is around 11.39 cm to access the center of the disc space, while it may decrease to 8.30 cm when planning an approach to the foraminal or paramedian space. These results consubstantiate and provide evidence to support the skin incision distance to the midline previously used to approach L5S1 for disc herniations or stenotic pathology and endoscopic-assisted transforaminal interbody fusion.[13,25]

Despite the information described, individual imaging must be accessed preoperatively for each patient. The traditional measurements used to determine the skin incision and approach trajectory in a 2-dimensional setting (**Figure 4**) cannot provide detailed and accurate information on the potential limitations of an L5S1 endoscopic transforaminal access. The methodology used in this paper allows for planning skin incision, identifying possible constraints for transforaminal L5S1 access, planning eventual extended foraminoplasty, a trans-SAP or transiliac approach, or the need to be prepared to convert or choose *ab initio* an ipsilateral or contralateral interlaminar approach according to the pathology to be treated.

Strengths and Limitations

Our results were derived from a limited sample of 200 individuals and may not be extrapolated for the general population. Furthermore, LBP may be associated with several factors, namely disc, end plate, facet, and muscle changes. However, our study aimed to identify differences in the regional lumbosacral morphology of patients with chronic LBP that would interfere with the

Table 3. Iliac Crest Height and Intersection of the Ilium by the Projected Vectors of the Approach Angles, According to IC Grading System

Grade	ICPh	ICPi	Maximum Ilium Intersection	Minimum Ilium Intersection	No ICi
5	49	3	33	2	14
4	262	106	76	4	182
3	86	249	3	0	83
2	3	42	0	0	3
1	0	0	0	0	0
Total	400	400	112	6	282

ICPh, iliac crest highest point projection in the lumbar spine; ICPi, iliac crest intersection point with maximum approach angle vector projection in the lumbar spine; ICi, iliac crest intersection point with maximum approach angle vector; IC, iliac crest.

Table 4. Correlation Between Lumbopelvic Parameters and L5S1 Approach Parameters

	PI	Facet Angle	Maximum Ilium Intersection	ICPh	ICPi	ΔICh-SP	ΔICi-SP
PI		0.081*	−0.015†	0.203†	0.361†	−0.051*	−0.106*
		(0.106)	(0.767)	**(<0.001)**	**(<0.001)**	(0.311)	**(0.034)**
Facet angle	0.081*		0.303†	−0.005†	0.026†	−0.122*	0.004*
	(0.106)		**(<0.001)**	(0.924)	(0.610)	**(0.014)**	(0.937)
Maximum ilium intersection	−0.015†	0.303†		0.393†	0.240†	−0.012†	−0.216†
	(0.767)	**(<0.001)**		**(<0.001)**	**(<0.001)**	(0.813)	**(<0.001)**
ICPh	0.203†	−0.005†	0.393†		0.458†	0.081†	−0.312†
	(<0.001)	(0.924)	**(<0.001)**		**(<0.001)**	(0.104)	**(<0.001)**
ICPi	0.361†	0.026†	0.240†	0.458†		−0.005†	−0.208†
	(<0.001)	(0.610)	**(<0.001)**	**(<0.001)**		(0.920)	**(<0.001)**
ΔICh-SP	−0.051*	−0.122*	−0.012†	0.081†	−0.005†		0.232*
	(0.311)	**(0.014)**	(0.813)	(0.104)	(0.920)		**(<0.001)**
ΔICi-SP	−0.106*	0.004*	−0.216†	−0.312†	−0.208†	0.232*	
	(0.034)	(0.937)	**(<0.001)**	**(<0.001)**	**(<0.001)**	**(<0.001)**	

Pearson correlation coefficient was used for continuous variables and Spearman for ordinal variables; (*P* value). Bold indicates *P* value < 0.05.
ICPh, iliac crest highest point projection in the lumbar spine; ICPi, iliac crest intersection point with maximum approach angle vector projection in the lumbar spine; ΔICh-SP, distance between the higher point of the iliac crest (ICh) and the spinous process (SP); ΔICi-SP, iliac crest intersection point with the maxAA (ICi) to the spinous process (SP); PI, pelvic incidence.
*Pearson correlation coefficient
†Spearman

transforaminal L5S1 approach. For patient selection, our focus was on the symptoms, not the LBP's etiology. Nonetheless, we excluded several patients and participants with conditions that could confound the results.

The global spinal alignment was not evaluated, as conventional CT imaging is not very useful for analyzing spine balance since patients are in a supine position.[26] Nevertheless, to our knowledge, this is the first study to analyze specific pelvic and lumbosacral parameters and their correlations with transforaminal access to L5S1. Even so, global spinal alignment remains a good asset for investment in future research. Also, this study is the most comprehensive database providing data for setting preliminary reference access angles and skin incision planning values, IC height at ICi, and potential conflict to an L5S1 transforaminal approach.

Other limitations relate to the potentially time-consuming analysis compared to simple stand X-ray observation and radiation exposure, though these parameters are easily transposed to 3-dimensional magnetic resonance imaging. Current results will benefit with further correlation to surgical approach in clinical practice.

Table 5. Subgroup Analysis According to Ilium Intersection by Both Maximum and Minimum Approach Angles or Only in the Maximum Approach Angle Projected

Subgroup	Minimum Ilium Intersection + Maximum Ilium Intersection	Maximum Ilium Intersection Only
n	6	106
Mean ± SD (range)	1.26 ± 0.52 (0.72–2.21)	0.64 ± 0.35 (0.00–1.67)

SD, standard deviation.

CONCLUSIONS

Deep understanding and knowledge of patient anatomy will increase surgical procedures' safety, accuracy, and effectiveness. Our results comprehensively characterize lumbosacral morphology for L5S1 transforaminal access, setting preliminary reference values for access and working angles, its correlation to the IC, and reference values for skin incision planning. Intersection with the ilium correlates not only to the IC height at different points but also with higher facet joint angles and decreased intersection point distance to the SP. IC height was also shown to increase with higher PI. As traditionally measured by the projection of its highest point, the IC height does not correspond to the potential point of conflict with transforaminal access to L5S1, and only in a small percentage of cases will the IC eventually prevent this approach. Due to the pelvic anatomic differences between genders, potential conflict with the ilium is increased in the male population. Despite a significant increase in ICPi, LBP participants

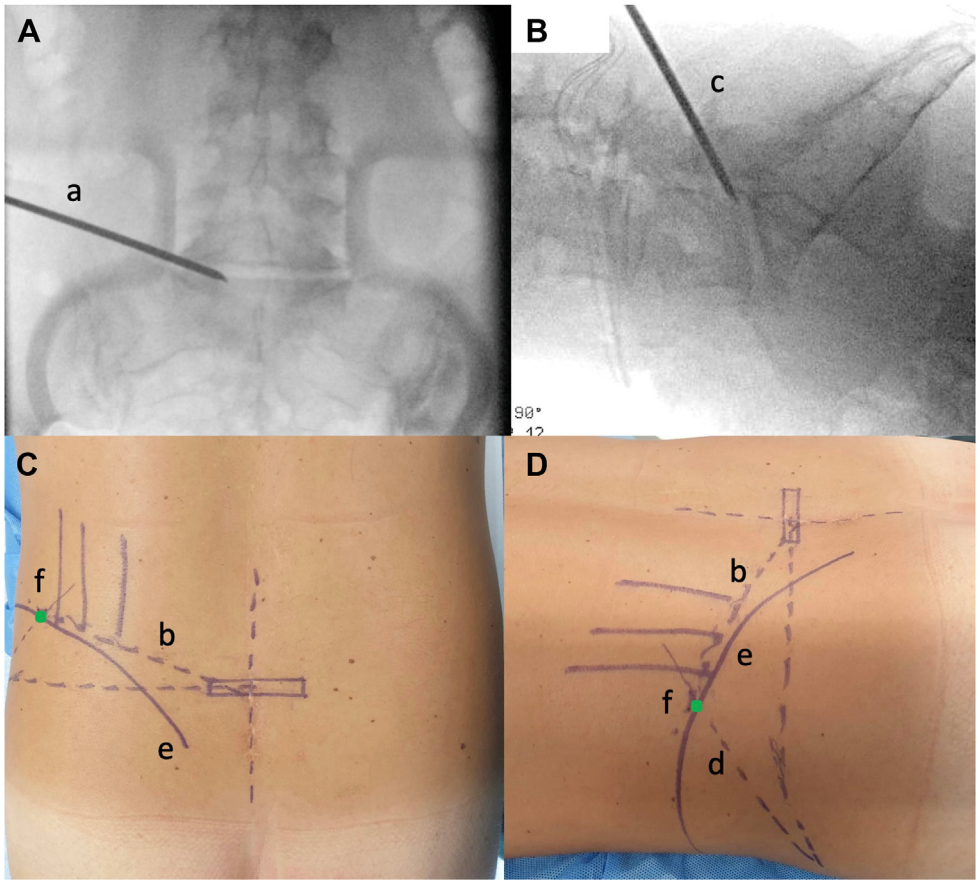

Figure 4. Skin incision and approach trajectory planning in a 2D setting. (**A**) Anteroposterior (AP) fluoroscopic image centered in L5S1 disc space. (**B**) Lateral fluoroscopic image centered in L5S1 disc space. (**C**) and (**D**) skin marking of the planned skin incision location and L5S1 transforaminal approach vectors. (**A**) Coronal trajectory line for L5S1 transforaminal approach; (**B**) skin projection of the coronal trajectory line for L5S1 transforaminal approach; (**C**) sagittal trajectory line for L5S1 transforaminal approach; (**D**) skin projection of the sagittal trajectory line for L5S1 transforaminal approach; (**E**) skin projection of the iliac crest; (F) location of planned skin incision—intersection of lines (**B**) and (**D**). 2D, 2-dimensional.

had overlapping morphometric and L5S1 approach parameters to the control group.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

José Miguel Sousa: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing — original draft. **António Serrano:** Data curation, Writing — review & editing. **Afonso Nave:** Conceptualization, Validation, Writing — review & editing. **Vasco Mascarenhas:** Conceptualization, Methodology, Validation, Writing — review & editing. **Paulo Nogueira:** Formal analysis, Methodology, Writing — review & editing. **Joao Gamelas:** Conceptualization, Project administration, Writing — review & editing. **José Guimarães Consciência:** Conceptualization, Methodology, Project administration, Visualization, Writing — review & editing.

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Conflict of interest statement: The present publication was funded by Fundação Ciência e Tecnologia, IP national support through CHRC (UIDP/04923/2020). The remaining authors have no conflicts to report.

Received 14 February 2023; accepted 7 April 2023

Citation: World Neurosurg. (2023). https://doi.org/10.1016/j.wneu.2023.04.026

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