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Pelvic Incidence and Iliac Venous Anatomy at L5–S1: A Radiologic Morphometric Study

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Research Article

Keywords: Pelvic incidence, Iliac veins, Vascular anatomy, Lumbosacral junction, Magnetic resonance imaging, Morphometry

Posted Date: October 5th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10692345/v1

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Additional Declarations: No competing interests reported.

Abstract

Purpose

The vein-free vascular corridor is an important anatomical factor influencing anterior access to the lumbosacral junction. This study aimed to characterize iliac venous anatomy at L5–S1 and its relationship with pelvic incidence (PI), focusing on corridor configuration and dimensions.

Methods

A consecutive cohort of 160 adults with standing full-spine radiographs and lumbosacral magnetic resonance imaging was analyzed. On axial images at L5–S1, the relationship between the iliac veins and anterior disc was assessed using a five-type classification of the vein-free vascular corridor. Corridor dimensions were quantified as the interiliac distance relative to total disc width. Associations with PI were assessed using linear and ordinal logistic regression, adjusted for age and sex.

Results

Mean age was 56.8 ± 15.2 years and mean PI was 52.8 ± 12.4°. Types III–IV accounted for 79.4% of cases. Disc window percentage increased progressively across vascular types, from 0% in Type 0 to 79.8% in Type IV ($p < 0.001$). PI was positively associated with disc window percentage, and this remained significant after adjustment for age and sex (adjusted $\beta = 0.45$ percentage points per degree; 95% CI 0.13–0.77; $p = 0.006$). Increasing PI was also associated with higher vascular corridor categories (adjusted OR 1.028 per degree; 95% CI 1.002–1.054; $p = 0.037$).

Conclusion

Pelvic incidence is associated with iliac venous anatomy at L5–S1. Increasing PI was associated with a wider vein-free vascular corridor and with progressively higher corridor categories, supporting a relationship between pelvic morphology and the transverse configuration of the iliac veins.

INTRODUCTION

The lumbosacral junction is characterized by a complex spatial relationship between the L5–S1 intervertebral disc and the iliac vascular structures. In particular, the position, caliber, and confluence of the iliac veins show substantial interindividual variability, resulting in marked differences in the portion of the anterior disc surface not covered by major venous structures [2, 9, 12]. This vein-free vascular corridor represents an anatomically relevant window for anterior access to the L5–S1 disc space. Imaging-based and anatomical studies have demonstrated considerable variability in its configuration and dimensions, emphasizing the importance of detailed assessment of regional vascular anatomy [8].

The clinical relevance of this anatomical variability is particularly evident during anterior lumbar interbody fusion (ALIF). Although ALIF provides direct access to the disc space and allows restoration of disc height and sagittal alignment, exposure of L5–S1 may require mobilization of the iliac vessels. Venous injury remains one of the most relevant approach-related complications and may result in significant morbidity [1, 4, 13, 15]. Consequently, the size and configuration of the vein-free vascular corridor may influence the technical complexity and safety of anterior exposure, making accurate characterization of iliac venous anatomy an important component of preoperative assessment.

The anatomical factors underlying this variability, however, remain incompletely understood. Pelvic morphology may contribute to the spatial arrangement of vascular structures at the lumbosacral junction. Pelvic incidence (PI) is a fixed anatomical parameter in adults that characterizes pelvic morphology and is closely related to sacral orientation, sacral slope, and pelvic tilt [6]. Variations in PI are associated with distinct lumbosacral morphotypes; a higher PI is generally associated with a more horizontal sacral orientation, whereas a lower PI corresponds to a more vertically oriented sacrum [10, 11]. These morphological differences may alter the spatial relationship between the L5–S1 disc, sacral plateau, and adjacent iliac vessels.

This potential relationship has also been suggested by surgical observation. During anterior exposure of L5–S1, the configuration of the iliac vessels and the available vein-free corridor vary considerably among patients, and differences in pelvic morphology appear to accompany distinct patterns of vascular exposure. Recent evidence has begun to establish a relationship between pelvic morphology and iliac venous anatomy at the lumbosacral junction. Darnis et al. [3] demonstrated that pelvic incidence is associated with the craniocaudal position of the iliocaval confluence, with higher PI corresponding to a more cranially positioned confluence and lower PI to a more caudal position closer to the L5–S1 disc. However, whether pelvic incidence is also associated with the transverse configuration and dimensions of the vein-free vascular corridor directly anterior to the L5–S1 disc remains unknown. Previous studies have characterized the vascular anatomy and feasibility of anterior access to L5–S1 [8], but the relationship between pelvic morphology and the width of the venous corridor available across the anterior disc has not been specifically investigated.

The purpose of this study was therefore to characterize the iliac venous anatomy at L5–S1 using magnetic resonance imaging and to investigate its relationship with pelvic incidence, with particular emphasis on the configuration and dimensions of the vein-free vascular corridor. We hypothesized that differences in pelvic incidence would be associated with distinct patterns of iliac venous anatomy and vein-free corridor morphology at the lumbosacral junction.

MATERIALS AND METHODS

Study Design

This multicenter retrospective radiologic morphometric study evaluated the relationship between pelvic morphology and iliac venous anatomy at the L5–S1 level using standing radiographs and magnetic resonance imaging (MRI). The study was conducted as part of an institutional research line focused on morphometric assessment of anatomical corridors relevant to anterior lumbar approaches.

Study Population

Adult patients (≥ 18 years) who underwent both standing full-spine radiographs and lumbosacral magnetic resonance imaging (MRI) between July 2019 and November 2025 were eligible for inclusion. Imaging studies were required to be of diagnostic quality and obtained within a clinically acceptable interval to ensure anatomical correspondence between spinopelvic and vascular assessments. Demographic and clinical variables included age, sex, race/ethnicity, and underlying spinal pathology.

Exclusion Criteria

Patients were excluded if they had previous lumbosacral spine surgery, spinal trauma, tumor, or infection; a history of major abdominal or retroperitoneal surgery; or incomplete or poor-quality imaging precluding reliable anatomical measurements.

Imaging Analysis and Morphometric Measurements

Spinopelvic parameters. Standing full-spine radiographs were analyzed to measure pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS) according to standardized definitions. Measurements were performed using validated digital planning software. PI was analyzed as a continuous morphometric variable and, for categorical analyses, patients were stratified into three groups: low PI (< 45°), intermediate PI (45°–60°), and high PI (> 60°).

Iliac venous anatomy and topographic corridor classification. Axial T2-weighted MRI images at the L5–S1 disc level were analyzed to characterize the spatial relationship between the iliac veins and the anterior disc. For topographic assessment, the transverse width of the L5–S1 disc was visually divided into five equal segments, each representing one-fifth of the disc width. Based on the position of the right and left iliac veins relative to these segments, the vein-free vascular corridor was classified as Type 0, absence of a vein-free corridor; Type I, corridor spanning > 0 to < 1/5 of the disc width; Type II, ≥ 1/5 to < 2/5; Type III, ≥ 2/5 to < 3/5; and Type IV, ≥ 3/5 of the disc width (Figs. 1, 2). This classification represented a categorical assessment of the topographic relationship between the iliac veins and the anterior surface of the L5–S1 disc.

Continuous morphometric assessment of the vascular corridor. Independently of the topographic classification, the transverse dimensions of the vein-free corridor were quantified on axial MRI. The interiliac distance was measured between the medial margins of the right and left iliac veins at the L5–

S1 disc level, and the total transverse disc width was measured on the same image. Because the images used for these measurements were not spatially calibrated, absolute linear dimensions were not analyzed. Instead, corridor size was expressed as a scale-independent ratio, calculated as the interiliac distance divided by total disc width × 100. This normalized measure was defined as the disc window percentage. Values greater than 100% were considered anatomically valid when the interiliac distance exceeded the transverse disc width (Fig. 3).

Thus, vascular anatomy was evaluated using two complementary approaches: a categorical topographic classification (Types 0–IV) describing the position of the iliac veins relative to the disc, and a continuous morphometric measurement (disc window percentage) quantifying the relative transverse dimension of the interiliac corridor.

Statistical Analysis

Descriptive statistics were calculated for demographic, spinopelvic, and vascular anatomical variables. Continuous variables were summarized as means and standard deviations, and categorical variables as frequencies and percentages.

The association between pelvic incidence (PI) and disc window percentage was assessed using Pearson correlation and linear regression, with additional adjustment for age and sex. Vascular corridor Types 0–IV were treated as ordered anatomical categories and analyzed using ordinal logistic regression, with PI modeled both continuously and categorically; low PI served as the reference group. Adjusted models included age and sex, and the proportional-odds assumption was evaluated. Odds ratios (ORs) with 95% confidence intervals (CIs) were reported.

Disc window percentage was compared across vascular corridor types using one-way ANOVA, with Kruskal–Wallis analysis as a nonparametric sensitivity analysis. Interobserver reliability was assessed using linearly weighted Cohen's kappa for vascular corridor classification and a two-way, single-measurement, absolute-agreement intraclass correlation coefficient [ICC(A,1)] for PI measurements, both with 95% CIs.

Statistical significance was set at $p < 0.05$.

Ethical Considerations

The study was approved by the institutional Research Ethics Committee of Instituto Columna, Belo Horizonte, Brazil (CAAE 35586520.7.0000.5135). The requirement for informed consent was waived because of the retrospective analysis of routinely acquired imaging data.

Artificial intelligence–assisted tools were used for language editing and for formatting the manuscript and its tables. No text content, data, analyses, or figures were generated by artificial intelligence. All authors take full responsibility for the content of the manuscript.

RESULTS

A total of 160 patients were included, with a mean age of 56.8 ± 15.2 years; 94 (58.8%) were female. Degenerative disc disease was the most common underlying spinal pathology (78.8%). Mean pelvic incidence (PI) was 52.8 ± 12.4°, mean pelvic tilt was 17.4 ± 8.5°, and mean sacral slope was 35.6 ± 10.3°. Patients were distributed among low- (30.6%), intermediate- (38.8%), and high-PI (30.6%) groups. The mean disc window percentage was 60.5 ± 26.4% (Table 1).

Table 1
Baseline and anatomical characteristics of the study population (n = 160)

Variable	Value
Age, years, mean ± SD	56.8 ± 15.2
Sex, n (%)	
Female	94 (58.8%)
Male	65 (40.6%)
Missing[a]	1 (0.6%)
Race, n (%)	
White	154 (96.3%)
Black	5 (3.1%)
Missing[a]	1 (0.6%)
Underlying spinal pathology, n (%)	
Degenerative disc disease (DDD)	126 (78.8%)
Other spinal pathology	34 (21.2%)
Pelvic incidence (PI), °, mean ± SD	52.8 ± 12.4
Pelvic tilt (PT), °, mean ± SD	17.4 ± 8.5
Sacral slope (SS), °, mean ± SD	35.6 ± 10.3
PI group, n (%)[b]	
Low PI (< 45°)	49 (30.6%)
Intermediate PI (45°–60°)	62 (38.8%)
High PI (> 60°)	49 (30.6%)
Vein-free vascular corridor type at L5–S1, n (%)	
Type 0	3 (1.9%)
Type I	8 (5.0%)

Values are presented as mean ± SD or n (%). Percentages may not total 100% because of rounding. SD, standard deviation; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope. [a] Sex and race data were unavailable for one participant. [b] PI groups were defined as low (< 45°), intermediate (45°–60°), and high (> 60°). [c] Disc window percentage was calculated as the interiliac distance divided by the total transverse disc width × 100; values > 100% are anatomically possible when the interiliac distance exceeds the disc width.

Variable	Value
Type II	22 (13.8%)
Type III	43 (26.9%)
Type IV	84 (52.5%)
Disc window, %, mean ± SD[c]	60.5 ± 26.4

Values are presented as mean ± SD or n (%). Percentages may not total 100% because of rounding. SD, standard deviation; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope. [a] Sex and race data were unavailable for one participant. [b] PI groups were defined as low (< 45°), intermediate (45°–60°), and high (> 60°). [c] Disc window percentage was calculated as the interiliac distance divided by the total transverse disc width × 100; values > 100% are anatomically possible when the interiliac distance exceeds the disc width.

Iliac venous anatomy at L5–S1 showed substantial interindividual variability. Type IV was the most frequent vein-free vascular corridor configuration, occurring in 84 patients (52.5%), followed by Type III in 43 (26.9%), Type II in 22 (13.8%), Type I in 8 (5.0%), and Type 0 in 3 (1.9%). Types III and IV together accounted for 79.4% of the cohort. Disc window percentage increased progressively across corridor types, from 0.0 ± 0.0% in Type 0 to 7.6 ± 4.1% in Type I, 33.8 ± 5.4% in Type II, 50.5 ± 6.1% in Type III, and 79.8 ± 16.9% in Type IV. Differences across types were significant on both one-way ANOVA ($F(4,155) = 125.58$, $p < 0.001$) and Kruskal–Wallis analysis ($H = 129.30$, $p < 0.001$) (Table 2).

Table 2
Disc window percentage according to vein-free vascular corridor type at L5–S1

Vein-free vascular corridor type	n	Disc window (%), mean ± SD
Type 0[a]	3	0.0 ± 0.0
Type I	8	7.6 ± 4.1
Type II	22	33.8 ± 5.4
Type III	43	50.5 ± 6.1
Type IV	84	79.8 ± 16.9

Values are presented as mean ± SD. Disc window percentage differed significantly across vascular corridor types (one-way ANOVA, $F(4,155) = 125.58$, $p < 0.001$), with consistent results on Kruskal–Wallis analysis ($H = 129.30$, $p < 0.001$). SD, standard deviation. [a] Denotes absence of a vein-free vascular corridor.

When PI and disc window percentage were analyzed as continuous morphometric variables, PI showed a positive correlation with disc window percentage (Pearson $r = 0.239$, $p = 0.002$; Fig. 4). In unadjusted linear regression, each 1° increase in PI was associated with a 0.51-percentage-point increase in disc window ($\beta = 0.51$; 95% CI 0.18–0.83; $p = 0.002$; $R^2 = 0.057$). The association remained significant after adjustment for age and sex (adjusted $\beta = 0.45$ percentage points per degree; 95% CI 0.13–0.77; $p =$

0.006) (Table 3). The scatter plot demonstrated the positive linear relationship between PI and relative interiliac corridor width, with the fitted regression line and its 95% confidence interval (Fig. 4).

Table 3
Association of pelvic incidence with L5–S1 venous corridor morphology

Outcome	Predictor / Model	Effect estimate	95% CI	p value
Disc window (%)[a]	PI, per 1° increase — unadjusted linear regression	β = 0.51	0.18–0.83	0.002
Disc window (%)	PI, per 1° increase — adjusted for age and sex	β = 0.45	0.13–0.77	0.006
Vascular Type 0–IV[b]	PI, per 1° increase — unadjusted ordinal logistic regression	OR = 1.029	1.004–1.055	0.022
Vascular Type 0–IV	PI, per 1° increase — adjusted for age and sex	OR = 1.028	1.002–1.054	0.037
Vascular Type 0–IV	Intermediate vs low PI — adjusted	OR = 1.52	0.75–3.10	0.246
Vascular Type 0–IV	High vs low PI — adjusted	OR = 2.48	1.13–5.45	0.024

Models were adjusted for age and sex as indicated. The proportional-odds assumption was not significantly violated. PI, pelvic incidence; OR, odds ratio; CI, confidence interval. [a] β represents the change in disc window percentage points per 1° increase in pelvic incidence. [b] Odds ratios from ordinal logistic regression represent the cumulative odds of belonging to a higher vascular corridor category.

A complementary ordinal analysis showed that increasing PI was also associated with progressively higher vascular corridor categories. In unadjusted ordinal logistic regression, each 1° increase in PI was associated with greater cumulative odds of belonging to a higher corridor type (OR 1.029; 95% CI 1.004–1.055; p = 0.022). This association persisted after adjustment for age and sex (adjusted OR 1.028 per degree; 95% CI 1.002–1.054; p = 0.037), corresponding to approximately 31% greater odds of belonging to a higher corridor category for each 10° increase in PI. In the PI group-based analysis, high PI was associated with higher vascular corridor categories compared with low PI (adjusted OR 2.48; 95% CI 1.13–5.45; p = 0.024), whereas the intermediate-PI group did not differ significantly from the low-PI group (adjusted OR 1.52; 95% CI 0.75–3.10; p = 0.246) (Table 3). The proportional-odds assumption was not significantly violated.

The descriptive distribution of corridor types across PI groups was consistent with this ordinal shift. Type IV accounted for 36.7% of patients with low PI, 54.8% of those with intermediate PI, and 65.3% of those with high PI. Conversely, Type II decreased from 20.4% in the low-PI group to 14.5% in the intermediate-PI group and 6.1% in the high-PI group (Table 4).

Table 4
Distribution of vein-free vascular corridor types according to pelvic incidence group

PI group[a]	Type 0	Type I	Type II	Type III	Type IV	Total
Low PI (< 45°)	1 (2.0)	1 (2.0)	10 (20.4)	19 (38.8)	18 (36.7)	49
Intermediate PI (45°–60°)	1 (1.6)	4 (6.5)	9 (14.5)	14 (22.6)	34 (54.8)	62
High PI (> 60°)	1 (2.0)	3 (6.1)	3 (6.1)	10 (20.4)	32 (65.3)	49
Total[b]	**3 (1.9)**	**8 (5.0)**	**22 (13.8)**	**43 (26.9)**	**84 (52.5)**	**160**

Values are n (%). Types 0–IV represent ordered anatomical categories based on the topographic relationship of the iliac veins to the L5–S1 disc. PI, pelvic incidence. [a] Percentages within the low-, intermediate-, and high-PI rows are calculated within each PI group. [b] Percentages in the total row are calculated for the entire cohort.

Interobserver reliability was high for both anatomical measurements. PI measurement demonstrated an ICC(A,1) of 0.944 (95% CI 0.895–0.970). For the vein-free vascular corridor classification, exact agreement between examiners was 92.5%, agreement within one category was 97.5%, and the linearly weighted Cohen's κ was 0.907 (95% CI 0.762–1.000) (Table 5).

Table 5
Interobserver reliability of pelvic incidence measurement and vein-free vascular corridor classification

Variable	Assessment	n	Reliability estimate	95% CI
Pelvic incidence	Examiner 1 vs. Examiner 2	39	ICC(A,1) = 0.944[a]	0.895–0.970
Vein-free vascular corridor classification[b]	Exact agreement	40	92.5%	-
	Agreement within ± 1 category	40	97.5%	-
	Linearly weighted Cohen's κ	40	κ = 0.907	0.762-1.000

ICC, intraclass correlation coefficient; CI, confidence interval. Exact agreement and agreement within ± 1 category are also reported. [a] Pelvic incidence reliability was assessed using ICC(A,1), based on a two-way model, single measurement, and absolute agreement. [b] Interobserver agreement for the vein-free vascular corridor classification was assessed using linearly weighted Cohen's κ.

DISCUSSION

This multicenter radiologic morphometric study demonstrates that pelvic incidence is associated with iliac venous anatomy at the L5–S1 level. The principal finding was a positive relationship between PI and

the relative transverse width of the vein-free vascular corridor: increasing PI was associated with a larger disc window, and this association remained significant after adjustment for age and sex. A complementary ordinal analysis showed a parallel shift toward higher vascular corridor categories with increasing PI. Together, these findings support a reproducible anatomical relationship between pelvic morphology and the transverse configuration of the iliac venous structures at the lumbosacral junction.

Substantial interindividual variability in iliac venous anatomy was observed, consistent with previous imaging and anatomical studies of the L5–S1 vascular region [7, 8, 14]. Type IV was the most frequent configuration, whereas Types III and IV together accounted for approximately four fifths of the cohort. Importantly, the categorical vascular classification corresponded to a clear morphometric gradient. Mean disc window percentage increased progressively from 0% in Type 0 to approximately 80% in Type IV, with highly significant differences across categories. This finding supports the anatomical validity of the classification and indicates that the topographic position of the iliac veins relative to the L5–S1 disc reflects measurable differences in the transverse interiliac corridor.

The most relevant inferential finding was obtained when PI and disc window percentage were preserved as continuous variables. Each 1° increase in PI was associated with an approximately 0.5-percentage-point increase in disc window, and the association persisted after adjustment for age and sex. Although the proportion of variance explained by PI alone was modest, this is anatomically plausible because vascular configuration is likely influenced by multiple factors beyond pelvic morphology, including vessel caliber, branching and confluence patterns, body habitus, and other regional anatomical characteristics [7, 8, 14]. Thus, PI should be interpreted as one component of a multifactorial anatomical relationship rather than as a solitary determinant of vascular corridor dimensions.

The ordinal analysis provided complementary evidence. When vascular Types 0-IV were treated according to their inherent anatomical order, increasing PI was associated with higher corridor categories both before and after adjustment for age and sex. A 10° increase in PI corresponded to approximately 31% greater cumulative odds of belonging to a higher vascular corridor category. Likewise, patients with high PI had more than twice the adjusted odds of belonging to a higher corridor category compared with those with low PI. The descriptive distribution was consistent with this pattern, with the prevalence of Type IV increasing progressively from the low- to the high-PI group.

These findings extend recent observations linking spinopelvic morphology to iliac venous anatomy. Darnis et al. [3] demonstrated that PI is associated with the craniocaudal position of the iliocaval confluence, with higher PI corresponding to a more cranially positioned confluence and lower PI to a more caudal position closer to the L5–S1 level. The present study evaluates a different but complementary anatomical dimension. Rather than the longitudinal position of the iliocaval confluence, we assessed the transverse configuration and relative width of the vein-free corridor directly anterior to the L5–S1 disc. Considered together, these findings suggest that pelvic morphology may be associated with iliac venous anatomy in more than one spatial plane, influencing both the craniocaudal position of the venous confluence and the transverse interiliac space at the lumbosacral junction.

A potential anatomical explanation lies in the relationship between PI and sacral orientation. Pelvic incidence is a fixed morphological parameter that is closely related to the spatial orientation of the sacrum and lumbosacral junction [6]. Higher PI is generally associated with a more horizontal sacral orientation, whereas lower PI is associated with a more vertical configuration. Variations in sacral orientation may therefore modify the three-dimensional relationship between the L5–S1 disc, sacral promontory, and adjacent iliac vessels. The present findings do not establish the precise mechanism underlying this relationship, but they provide quantitative evidence that pelvic morphology and iliac venous configuration are not anatomically independent.

Previous imaging and anatomical investigations have documented marked variability in the position of the iliac veins and iliocaval junction and have proposed classifications aimed at characterizing the vascular anatomy relevant to anterior access to L5–S1 [7, 8, 14]. Morphometric studies of surgical corridors have likewise demonstrated substantial anatomical variability across individuals and populations [5]. These studies established the importance of preoperative vascular assessment but generally evaluated vascular configuration independently of spinopelvic morphology. The present study adds a complementary morphometric perspective by demonstrating that a fixed pelvic parameter is associated with both the continuous width and the ordered topographic configuration of the L5–S1 venous corridor.

The surgical relevance of this anatomical relationship should be interpreted cautiously. Anterior lumbar interbody fusion at L5–S1 requires exposure in close proximity to the iliac vessels, and venous injury remains an important approach-related complication [1, 4, 13, 15]. A wider vein-free corridor may theoretically reduce the degree of venous mobilization required during anterior exposure, whereas a narrow corridor may impose greater anatomical constraints [8, 14]. However, the present study did not evaluate intraoperative vessel mobilization, operative difficulty, vascular injury, blood loss, or other surgical outcomes. Accordingly, vascular corridor dimensions should not be interpreted as direct measures of procedural safety. Rather, PI may serve as an additional anatomical marker that helps contextualize the vascular configuration observed on preoperative imaging, while direct assessment of the vessels remains essential.

The high interobserver reliability observed for both PI measurement and vascular corridor classification further supports the reproducibility of the proposed anatomical assessment. PI measurements demonstrated excellent agreement between examiners, while the vascular classification showed high weighted kappa and exact agreement exceeding 90%. These findings indicate that both components of the morphometric assessment can be applied consistently using routine radiographic and MRI examinations.

Several limitations should be acknowledged. First, the retrospective imaging-based design precludes causal inference and limits conclusions to anatomical associations. Second, vascular anatomy was assessed on static MRI; intraoperative vessel mobility, dynamic displacement, adhesions, and other factors affecting actual exposure were not evaluated. Third, operative outcomes were unavailable,

preventing direct assessment of whether corridor width or vascular type predicts surgical difficulty or vascular complications. Fourth, although the multicenter design improves generalizability, differences in imaging acquisition protocols may have introduced measurement variability. Fifth, the study population consisted predominantly of patients with degenerative spinal pathology who were potential candidates for anterior L5–S1 surgery. Although this population is clinically relevant to the anatomical question investigated, the findings may not be directly generalizable to patients with major spinal deformity, high-grade spondylolisthesis, previous anterior surgery, or complex vascular anomalies. Finally, PI explained only a modest proportion of the variability in disc window dimensions, indicating that iliac venous configuration is likely multifactorial and influenced by additional anatomical and patient-specific factors.

Despite these limitations, this study provides quantitative evidence that pelvic morphology is associated with iliac venous anatomy at L5–S1. By demonstrating relationships between PI and both the continuous transverse dimensions and the ordinal topographic configuration of the vein-free vascular corridor, the present findings complement recent evidence regarding the craniocaudal position of the iliocaval confluence [3]. Together, these observations support a broader anatomical concept in which spinopelvic morphology contributes to the three-dimensional organization of venous structures at the lumbosacral junction. Future prospective studies integrating radiologic morphometry, three-dimensional vascular assessment, and operative findings are needed to determine the clinical implications of this anatomical relationship

CONCLUSION

Pelvic incidence is associated with iliac venous anatomy at L5–S1. Increasing PI was associated with a wider vein-free vascular corridor and with progressively higher vascular corridor categories, supporting a relationship between pelvic morphology and the transverse configuration of the iliac veins at the lumbosacral junction. These findings provide a morphometric basis for further investigation of the relationship between spinopelvic morphology, vascular anatomy, and anterior surgical access to L5–S1

Declarations

Funding This study received no financial support from any public, commercial, or not-for-profit funding agency.

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Ethics approval This retrospective study involving human participants was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the institutional Research Ethics Committee of Instituto Columna, Belo Horizonte, Brazil (CAAE 35586520.7.0000.5135).

Consent to participate The requirement for informed consent was waived by the Research Ethics Committee in view of the retrospective nature of the study and the use of routinely acquired imaging

data.

Consent to publish All imaging data presented are fully anonymised and contain no identifying information; the requirement for consent to publish was therefore waived.

Data availability The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author contribution All authors contributed to the study as follows:

AD Carvalho: Protocol/project development, Data collection or management

CM Menezes: Protocol/project development, Data collection or management

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Figures

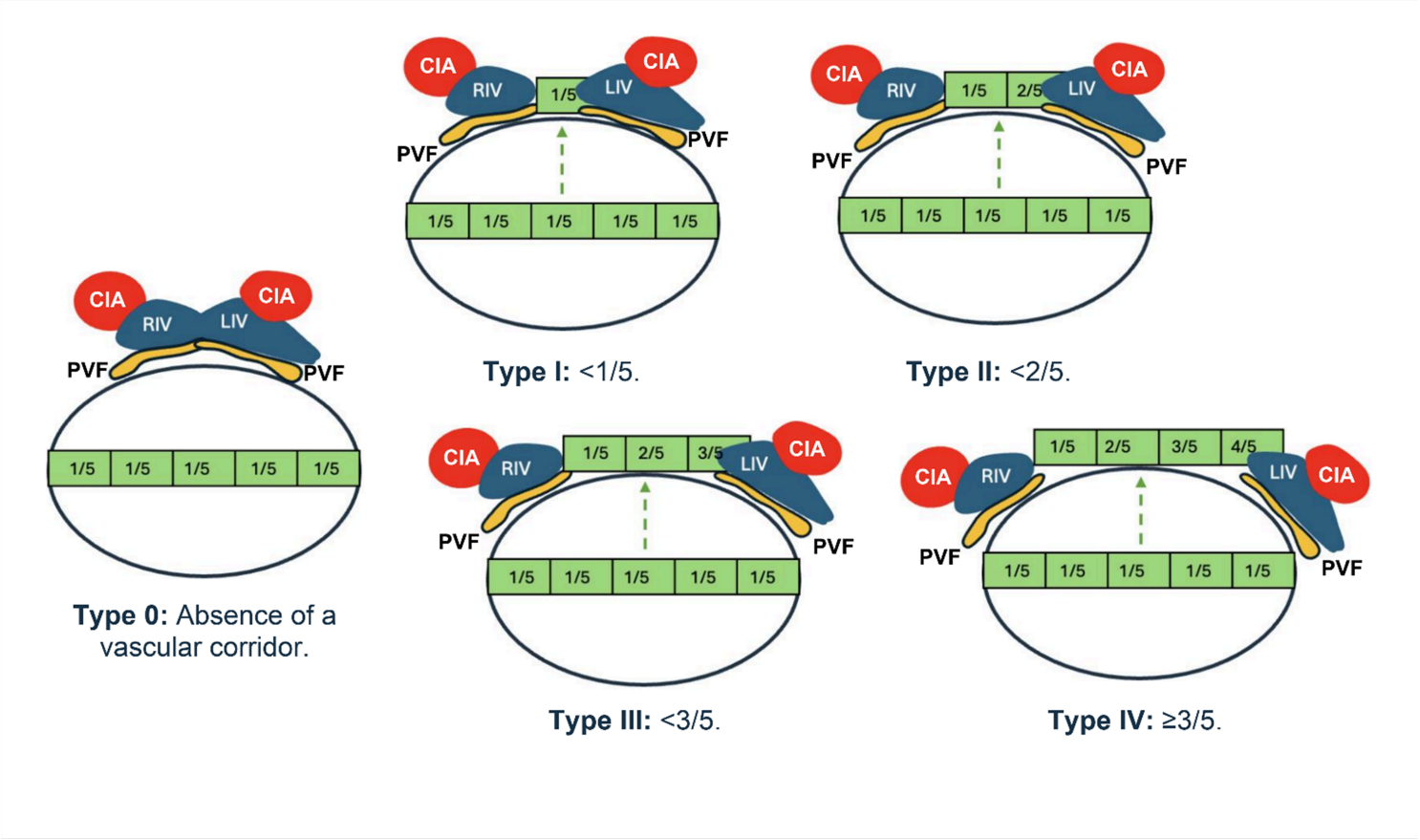


Figure 1

Schematic representation of the vein-free vascular corridor classification at the L5–S1 level based on the proportion of the anterior disc width free of major venous structures. The disc space is divided into five equal segments. Type 0 represents absence of a vein-free vascular corridor. Type I corresponds to a corridor spanning >0 to <1/5 of the disc width; Type II, ≥1/5 to <2/5; Type III, ≥2/5 to <3/5; and Type IV, ≥3/5. The relative positions of the right iliac vein (RIV) and left iliac vein (LIV) determine the available corridor and potential anterior disc accessibility. Iliac veins are shown in blue, common iliac arteries in red, and perivascular fat in yellow; the green segments indicate the fifths of the transverse disc width and the dashed green arrow indicates the vein-free corridor. The arteries and the perivascular fat are shown for anatomical orientation only and were not included in the classification, which was based on the position of the iliac veins. CIA, common iliac artery; PVF, perivascular fat; RIV, right iliac vein; LIV, left iliac vein

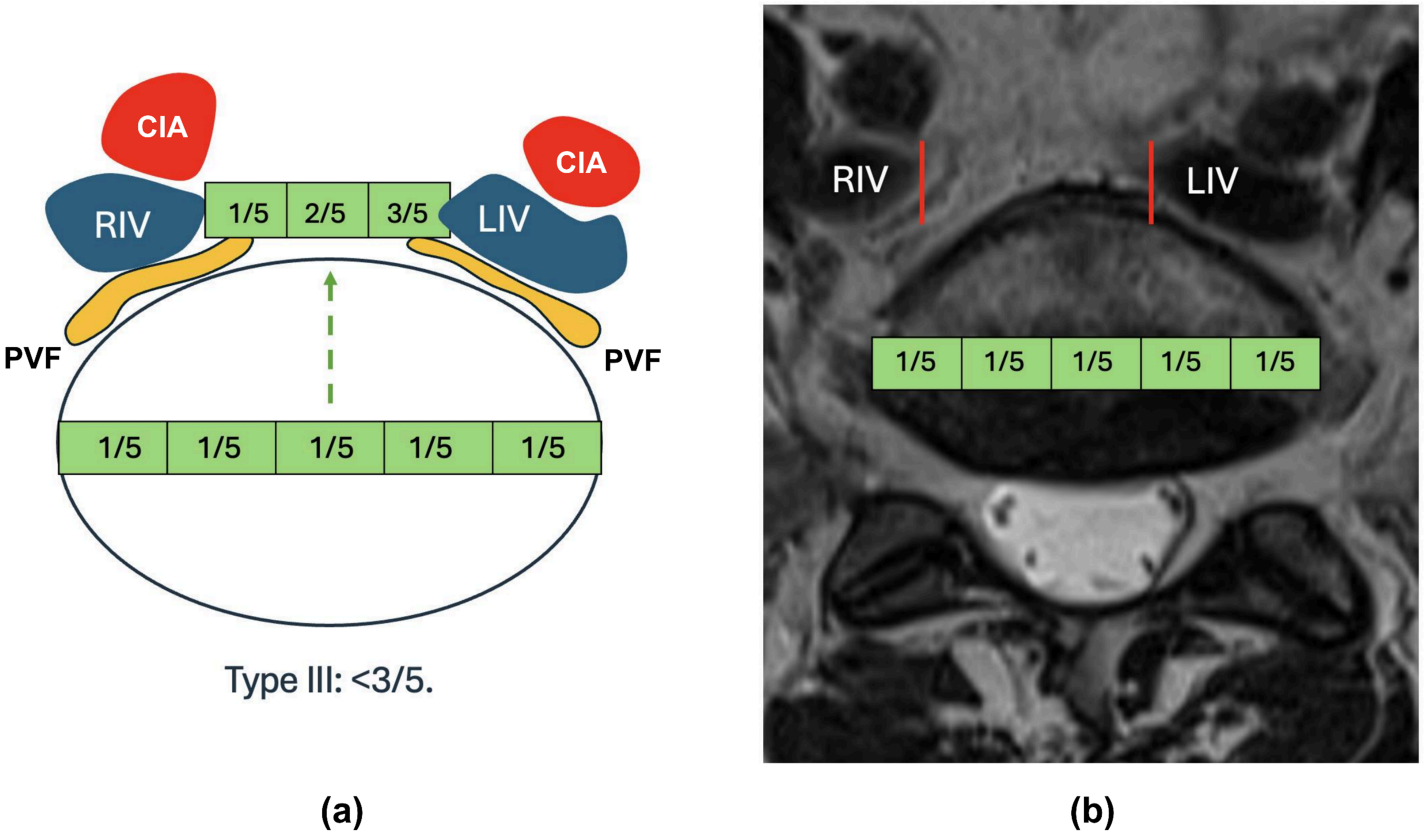


Figure 2

Illustrative example of a Type III vein-free vascular corridor at L5–S1. The schematic representation (a) and corresponding axial MRI image (b) demonstrate a corridor occupying <3/5 of the anterior disc width, determined by the relative positions of the right iliac vein (RIV) and left iliac vein (LIV). In (a), the iliac veins are shown in blue, the common iliac arteries in red, and the perivascular fat in yellow; the green segments indicate the fifths of the transverse disc width. In (b), the red vertical bars mark the medial margins of the right and left iliac veins. The arteries and the perivascular fat are shown for anatomical orientation only and were not included in the classification. CIA, common iliac artery; PVF, perivascular fat; RIV, right iliac vein; LIV, left iliac vein

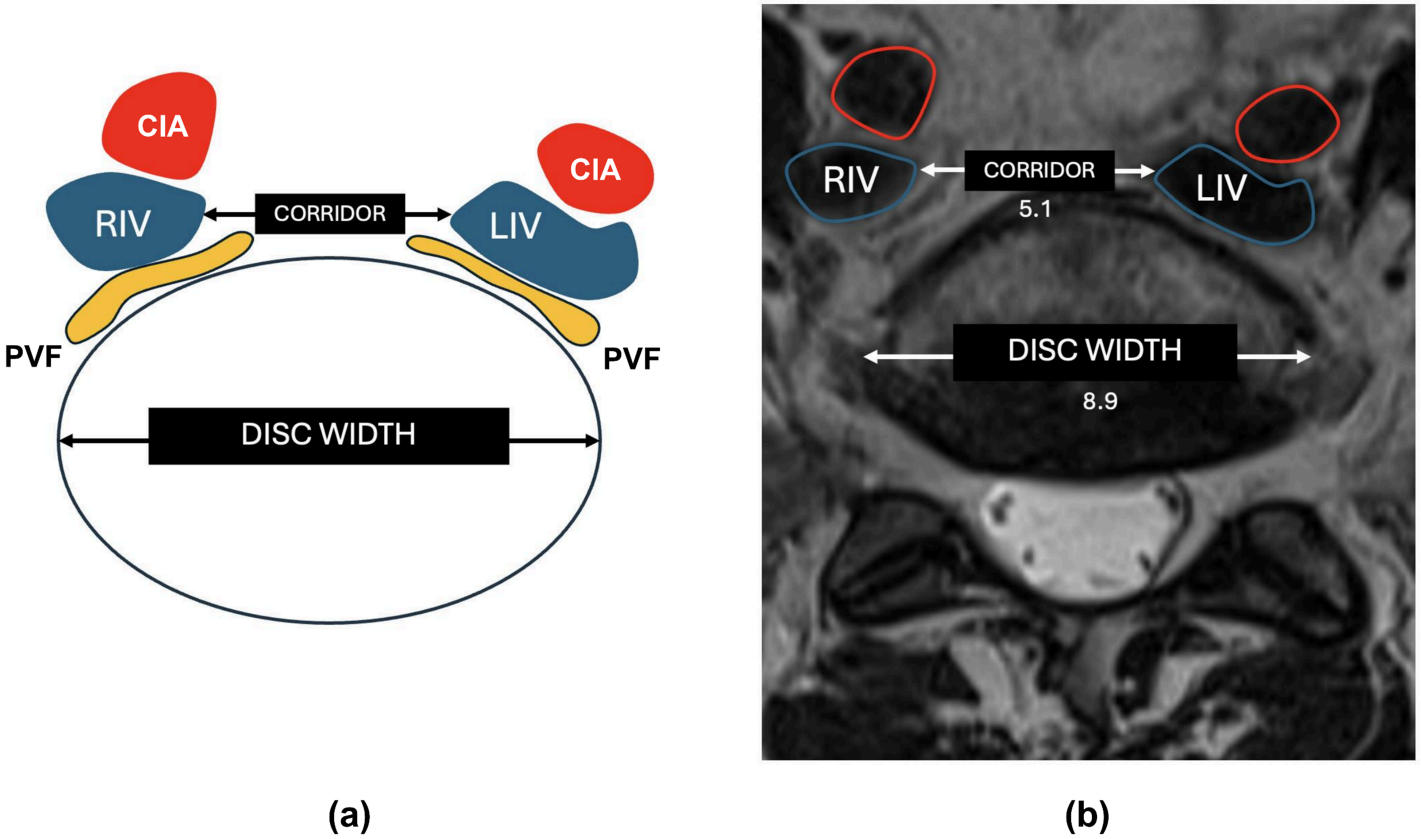


Figure 3

Measurement of the vein-free vascular corridor relative to total disc width at L5–S1. The schematic illustration (a) demonstrates the interiliac corridor and total transverse disc width, while the axial MRI image (b) shows the corresponding measurements. Because measurements were obtained from non-calibrated images, corridor dimensions were expressed as a scale-independent ratio of interiliac distance to total disc width. In this example, the corridor and disc widths measured 5.1 and 8.9 arbitrary units, respectively, resulting in a disc window of 57.3%. In (a), the iliac veins are shown in blue, the common iliac arteries in red, and the perivascular fat in yellow. In (b), the iliac veins are outlined in blue and the common iliac arteries in red. The arteries and the perivascular fat are shown for anatomical orientation only and were not included in the corridor measurement. CIA, common iliac artery; PVF, perivascular fat; RIV, right iliac vein; LIV, left iliac vein

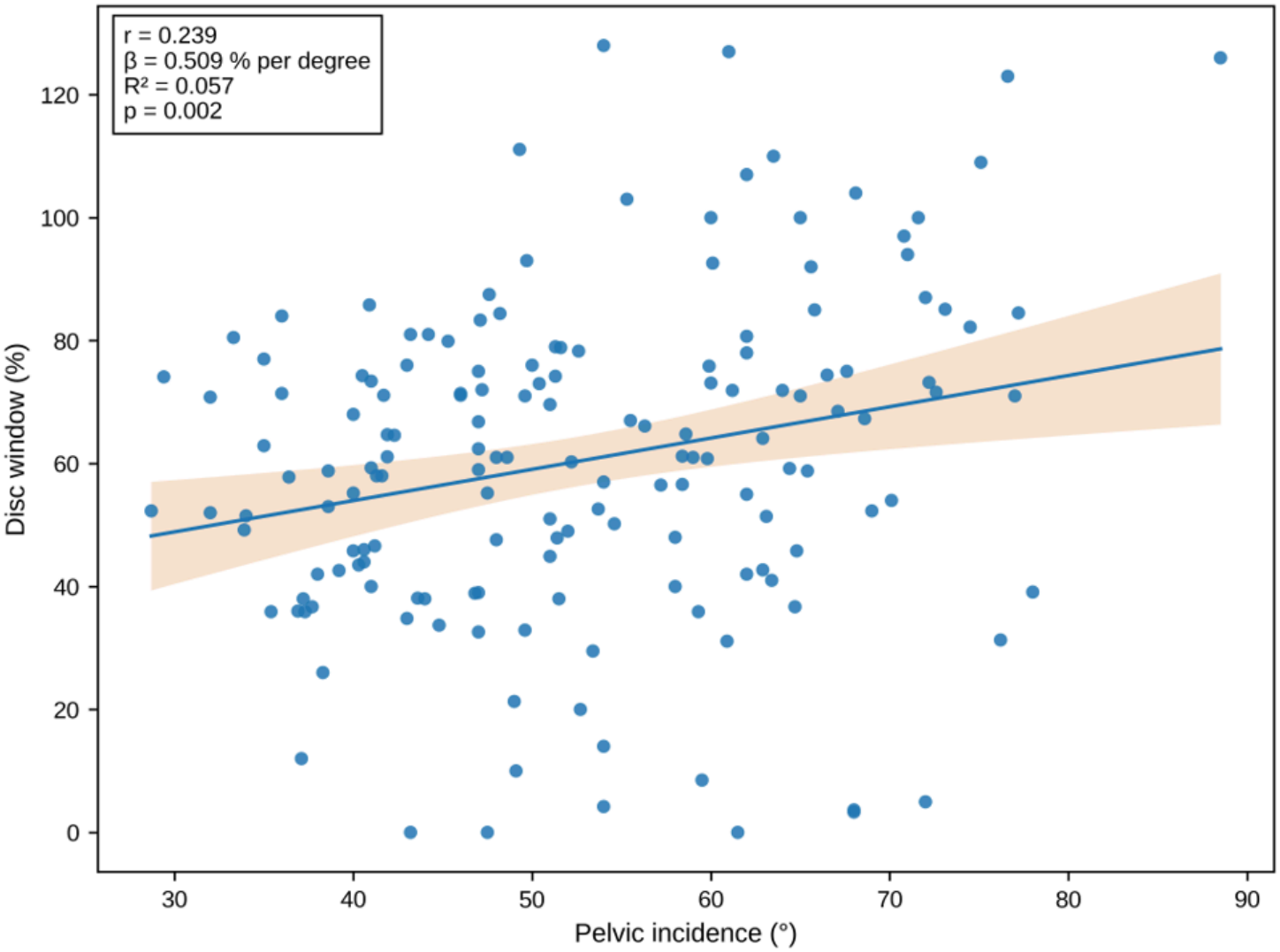


Figure 4

Association between pelvic incidence and disc window percentage at L5–S1. Scatter plot showing the relationship between pelvic incidence (PI) and disc window percentage. Each dot represents one patient. The solid line represents the fitted linear regression line, and the shaded area indicates the 95% confidence interval