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Spinopelvic Parameters in the Clinical and Functional Outcomes of Patients Submitted to Lumbar Interbody Fusion Surgery – A Prospective Study

Parâmetros espinopélvicos nos resultados clínicos e funcionais de pacientes submetidos a fusão intersomática lombar: um estudo prospectivo

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Abstract

Objectives The relevance of spinopelvic parameters in the patients' clinical and functional outcomes has been widely studied in long spinal fusion. Yet, the importance of the spinopelvic parameters in short-segment fusion surgeries needs further investigation. We analyzed the spinopelvic parameters and surgical outcomes of patients undergoing short-segment lumbar interbody fusion.

Materials and Methods An observational, prospective study was conducted between January and June 2021. We selected 25 patients with lumbar stenosis, with or without concomitant spondylolisthesis, undergoing transforaminal lumbar interbody fusion. Variables related to the patient, diagnosis, and surgery were collected. The clinical and functional outcomes were assessed using the Visual Analogue Scale for low-back and leg pain and the Oswestry Disability Index (ODI). The surgical outcomes and spinopelvic parameters were analyzed pre- and postoperatively.

Results There was a significant clinical and functional improvement after surgery ($p < 0.001$), with a mean ODI decrease of 63.6%. The variables of obesity, concomitant spondylolisthesis, absence of osteotomy, and two-level fusion were all associated with

Keywords
- spinopelvic parameters
- Oswestry disability index
- transforaminal lumbar interbody fusion

Renata Marques and Ana Cristina Silva contributed equally to the present work.

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lower levels of improvement after surgery ($p < 0.05$). Pelvic incidence minus lumbar lordosis (PI-LL) was the only parameter that significantly changed regarding the pre- and postoperative periods ($p < 0.05$). Before surgery, PI-LL $< -10°$ correlates with less low-back pain after surgery ($r = 0.435$; $p < 0.05$). Postoperatively, no correlation was found between surgical outcomes and all the spinopelvic parameters analyzed.

Conclusions The clinical and functional outcomes significantly improved with the surgical intervention but did not correlate with the change in spinopelvic parameters. Patients with preoperative PI-LL $< -10°$ seem to benefit the most from surgery, showing greater improvement in back pain.

Resumo

Objetivos A influência dos parâmetros espinopélvicos nos resultados clínicos e funcionais dos pacientes tem sido amplamente estudada nas cirurgias de fusão espinhal que envolvem longos segmentos. Contudo, a literatura é escassa acerca da fusão de segmentos curtos. Analisamos assim os parâmetros espinopélvicos e os resultados cirúrgicos de pacientes submetidos a fusão intersomática lombar de segmentos curtos.

Materiais e Métodos Realizou-se um estudo prospectivo observacional entre janeiro e junho de 2021. Selecionaram-se 25 pacientes com estenose lombar, com ou sem espondilolistese, submetidos a fusão intersomática lombar transforaminal. Colheram-se dados relacionados com o paciente, o diagnóstico e a cirurgia. Os resultados clínicos e funcionais foram avaliados por meio da Escala Visual Analógica para dor lombar e dos membros inferiores e pela Escala de Incapacidade de Oswestry (Oswestry Disability Index, ODI, em inglês). Os resultados cirúrgicos e os parâmetros espinopélvicos foram analisadas no pré e no pós-operatório.

Resultados Verificou-se uma melhoria clínica e funcional significativa após a cirurgia ($p < 0{,}001$), com redução média do ODI de 63,6%. As variáveis obesidade, espondilolistese concomitante, ausência de osteotomia e fusão de dois níveis associaram-se a menor melhoria no pós-operatório ($p < 0{,}05$). O único parâmetro que mudou significativamente antes e após a cirurgia ($p < 0{,}05$) foi a incidência pélvica menos a lordose lombar (IP-LL). No pré-operatório, uma IP-LL $< -10°$ correlacionou-se com menos dor lombar após a cirurgia ($r = 0{,}435$; $p < 0{,}05$). No pós-operatório, não houve correlação entre os resultados clínicos e funcionais e os parâmetros espinopélvicos.

Conclusão Os resultados clínicos e funcionais melhoraram significativamente após a cirurgia, mas não se correlacionam com a mudança dos parâmetros espinopélvicos. Pacientes com IP-LL $< -10°$ no pré-operatório apresentam maior melhoria da dor lombar no pós-operatório.

Palavras-chave
- parâmetros espinopélvicos
- escala de incapacidade de Oswestry
- fusão intersomática lombar transforaminal

Introduction

The human spine is a dynamic structure, and its articulation with the pelvis and lower limbs is fundamental for the verticality of the human skeleton. Even in the presence of variations in the degree of the normal curvature, the spine enables a balanced and harmonious distribution of forces, minimizing energy expenditure.[1,2] The disruption of sagittal alignment and spinopelvic changes, by aging or various spinal pathologies (reviewed by Mehta et al.[3]), results in spinal deformity and compensation mechanisms at the pelvis and lower limbs. These changes culminate in increased muscle tension and, consequently, pain symptoms and loss of quality of life.[4,5]

In 1992, Duval-Beaupère et al.[6] characterized the pelvic parameters, drawn from long-standing lateral X-rays. The main pelvic parameter is the pelvic incidence (PI), which corresponds to the angle between the sacrum and the femoral heads.[6] The PI is geometrically related with two additional pelvic parameters, the pelvic tilt (PT) and the sacral slope (SS), according to the equation: $PI = PT + SS$. The PI is a constant pelvic parameter, and the others vary to maintain the sagittal alignment.[3,7]

Harmonization between pelvic and spinal parameters is crucial. Schwab et al.[8] described a parameter relating PI and lumbar lordosis (LL) (PI minus LL: PI-LL) that quantifies the mismatch between pelvic morphology and lumbar curvature, and PI-LL $\pm 10°$ is the threshold to achieve spinopelvic sagittal alignment.

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Parameters that assess global alignment, such as the sagittal vertical axis (SVA), have also been described. This parameter corresponds to the horizontal distance between the C7 plumb line and the upper edge of the S1 vertebral body, which acquires a value < 50 mm depending on age.[5] This parameter should be used considering a temporal assessment for the same individual and not to compare different individuals.[9] Recently, Amabile et al.[10] showed that the odontoid hip axis angle (OD-HA) remains constant regardless of age, LL variations, or spinal compensatory mechanisms. This parameter hardly varies in asymptomatic patients (2° to −5°), and it is an excellent parameter for the assessment of the global sagittal alignment.[9]

It has been recognized that abnormal sagittal alignment changes after long-segment lumbar interbody fusion are related to worse clinical outcomes.[3,11] The persistence of low-back pain after lumbar interbody fusion surgery seems to be correlated with a more sacral verticalization, that is, excessive retroversion of the pelvis, with less SS and more PT, associated with a decrease in LL.[12] Also, older age, high preoperative PT, and a postoperative PI-LL ≥ 10° were identified as risk factors for reduced quality of life after lumbar interbody fusion surgery.[13] However, most studies are focused on long-segment fusion surgery, and few works have reported the influence of spinopelvic parameters in short-segment (one- or two-level) fusion surgeries.

The aim of the present study was to identify spinopelvic parameters that correlate with surgical outcomes in patients submitted to short-segment translumbar interbody fusion (TLIF). Therefore, we assessed spinopelvic parameters and clinical and functional outcomes through the Visual Analogue Scale (VAS) and the Oswestry Disability Index (ODI) respectively, before and after surgery. Additionally, we analyzed the relationship between patient, diagnosis, and surgery variables and the outcomes.

Methods

Study Design and Patient Selection

We conducted a prospective, observational, and descriptive study at the Neurosurgery Department of a district hospital in Portugal. All consecutive patients submitted to lumbar interbody fusion surgery from January to June 2021 were enrolled in the study.

Our cohort was selected based on the following inclusion criteria: 1) definitive diagnosis of lumbar spinal stenosis with or without concomitant spondylolisthesis, confirmed by an imaging exam; 2) full-spine lateral X-ray preoperatively (M0) and 6 months postoperatively (M6). We excluded patients with no informed consent and with a previous spine surgery or trauma to the spine, pelvis, or lower extremity.

Data Collection

Data were collected from the clinical records and interviews at M0 and M6. We used the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, United States) software, version 27.0 to compile the data anonymously.

The data collected included: age; gender; height and weight to calculate the body mass index (BMI); smoking habits; comorbidities according to the American Society of Anesthesiologists (ASA) physical status classification; depression as a comorbidity; previous lumbar surgery; definitive diagnosis confirmed by an imaging exam; surgical procedure and its complications; performance of osteotomy; number and level of involved spine segments; and the postoperative length of hospital stay and its complications.

Assessment of the Clinical and Functional Outcomes

Patient outcomes were prospectively assessed at M0 and M6. Clinical data was evaluated for pain symptoms (low-back and leg pain), which was quantified through the VAS score (0–10).[14] This score is a simple and subjective tool that enables the comparison of the intensity of pain over time. Functional disability was assessed by the ODI score (0–100%), which is divided into five categories: minimal disability (0% to 20%); moderate disability (21% to 40%); severe disability (41% to 60%); crippled (61% to 80%); and bedridden patients (81% to 100%).[15] The ODI and VAS scores were analyzed at M0 and M6. Global improvement was defined by the difference in scores between M0 and M6 (M0-M6).

Radiological Measurements

The spinopelvic parameters, namely the SVA, OD-HA, PI, PT, SS, LL, and PI-LL were obtained at M0 and M6, and their variation was calculated (ΔM6-M0). The measurements were performed by the same investigator using the Sectra software (Sectra AB, Linköping, Sweden). Full spine lateral X-rays were obtained with patients in the standard standing position.[16]

Surgical Procedure

The lumbar surgeries were performed by the same senior surgeon and involved a one- or two-level fusion through open TLIF. In this procedure, an interbody spacer with a bone graft (cage) was placed via the posterolateral transforaminal route into a distracted disk space along with a pedicle screw construct. In some patients, a Smith-Petersen osteotomy (SPO) was performed to improve LL. Intraoperative radiographs were performed to assess the cage and screws positions.

Statistical Analysis

Data were analyzed using the IBM SPSS Statistics software, version 27.0. The results are expressed as the mean ± standard deviation for the continuous variables and as absolute (n) and relative frequencies (%) for the qualitative ones.

Normality distribution was assessed through the Shapiro-Wilk Test ($n < 50$), skewness, kurtosis, and visual evaluation of the histograms. If the data were normally distributed, parametric statistics were applied. Comparisons between the same variable at M0 and M6 were analyzed through the paired *t*-test (for the continuous variables) and McNemar test (for the dichotomous variables). Bivariate analysis was performed for the outcomes according to the ODI and VAS scores regarding patient characteristics, diagnosis, surgery

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variables, and spinopelvic parameters. To test for homogeneity of the variances, the Levene test was performed, and the mean differences between outcomes and variables were obtained using the independent-samples *t*-test (for the dichotomous variables) or one-way analysis of variance (ANOVA, for the nominal variables) with Bonferroni (homogeneity of variance) as the post-hoc test. The effect size was calculated using Cohen D (d) or Eta-squared (η^2) respectively.

The association between spinopelvic parameters and the outcomes according to the ODI and VAS scores was evaluated with the Pearson correlation (for the continuous variables) and the Bissel correlation (for the dichotomous variables).

Statistical significance was defined as $p < 0.05$, with a confidence interval of 95% (95%CI).

Results

The study design chart is shown in ►**Fig. 1**.

Demographic and Surgical Descriptive Analysis

The mean age of the sample was of 55 ± 9.4 (range: 32 to 69) years. At the time of the surgery, most patients were non-smokers ($n = 21$; 84%) and 52% ($n = 13$) were obese (BMI ≥ 30 Kg/m^2), presenting a mean BMI of 28.8 ± 4.9 Kg/m^2 (range: 20.7 Kg/m^2 to 42 Kg/m^2). In terms of comorbidities, 80% of the patients were ASA 2, and 7 patients (28%) presented with depression (►**Table 1**).

We included patients with a definite diagnosis of spinal stenosis with or without spondylolisthesis. Foraminal stenosis was identified in 72% of the patients ($n = 18$), followed by both foraminal and central stenosis ($n = 4$; 16%) and central stenosis ($n = 3$; 12%). About 17 patients (68%) also presented spondylolisthesis grades 1 or 2 (►**Table 2**).

All patients underwent open TLIF surgery with a lordotic cage to preserve the disc height, and in 9 patients (36%), an SPO was performed. L4-L5 and L5-S1 were the segments most often intervened ($n = 22$; 88%), and the fusion involving two levels was only performed in 3 patients (12%). The only documented surgical complication was durotomy ($n = 3$; 12%). No cage migration or screw malposition was detected after surgery. The postoperative period developed with no serious complications, and only 1 patient presented with a self-limiting episode of fever with no need for antibiotics (►**Table 3**).

Analysis of the Spinopelvic Parameters

The detailed spinopelvic parameters measurements at M0 and M6 are presented in ►**Supplementary Table S1** (online only). In some cases, the M0 and/or M6 X-ray presented artifacts that prevented a correct analysis of the SVA in 4 patients ($n = 21$) and of the OD-HA in 3 patients ($n = 22$).

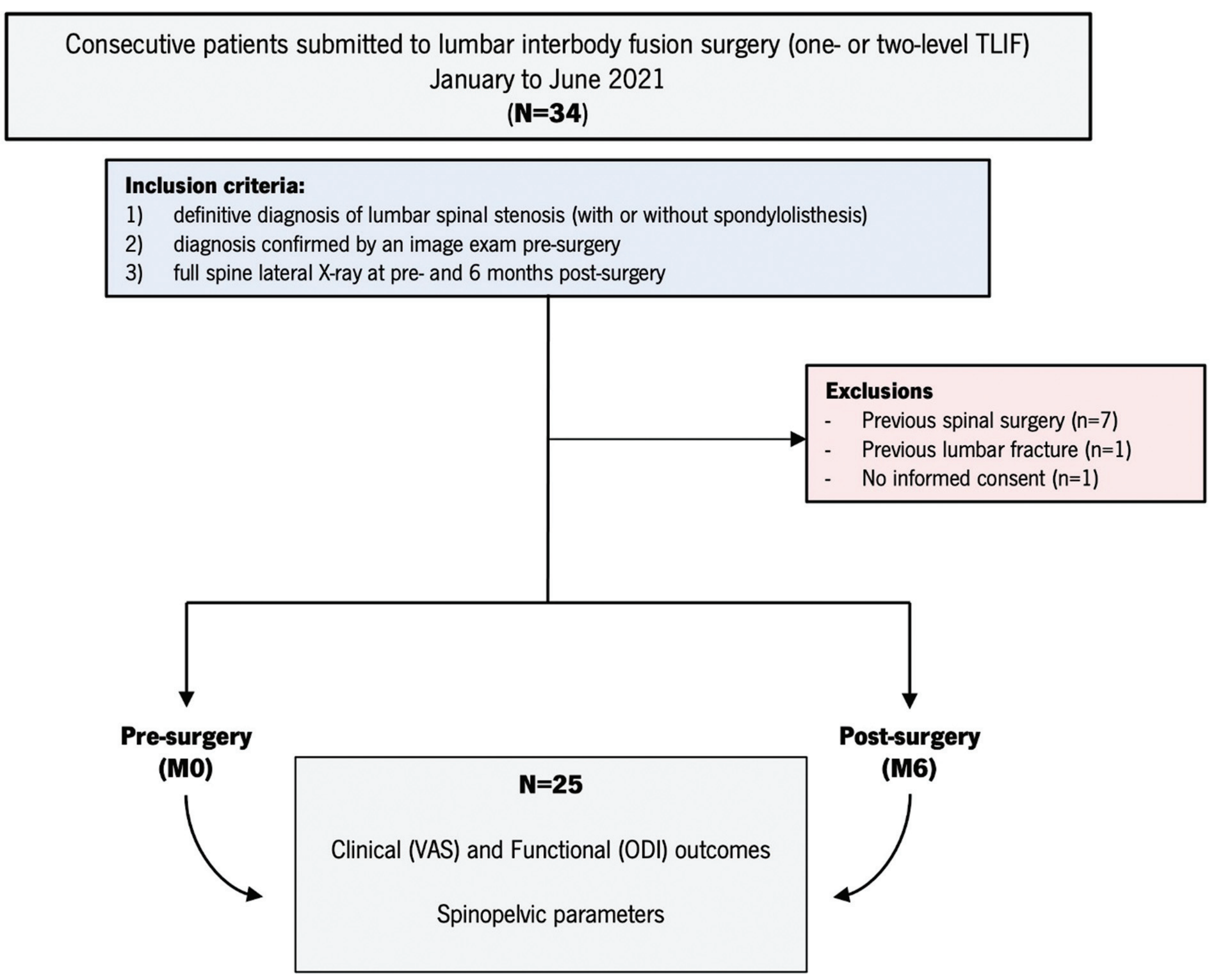

Fig. 1 Flowchart of the study design.

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Table 1 Descriptive analysis of the demographic data of the study sample

Demographic data		Value
Age (years)		55.0 ± 9.4 (range: 32 to 69)
Gender	Female	10 (40%)
	Male	15 (60%)
BMI (Kg/m^2)		28.8 ± 4.9 (range: 20.7 to 42)
	Normal	5 (20%)
	Overweight	7 (28%)
	Obesity I, II or III	13 (52%)
Smokers		4 (16%)
ASA classification	1	3 (12%)
	2	20 (80%)
	3	2 (8%)
Depression		7 (28%)

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, Body Mass Index.
Note: The continuous variables are presented as mean ± standard deviation (range) and the qualitative variables, as absolute (n) and relative (%) frequencies.

Table 2 Descriptive analysis of the diagnoses of the patients

Diagnosis		n (%)
Stenosis	Central	3 (12%)
	Foraminal	18 (72%)
	Central and foraminal	4 (16%)
Spondylolisthesis		17 (68%)
Type	Degenerative	8 (32%)
	Isthmic lysis	9 (36%)
Grade	1	9 (36%)
	2	8 (2%)

Table 3 Descriptive analysis of surgical intervention

		n (%)
Osteotomy	Smith-Petersen	9 (36%)
Fusion levels	1	22 (88%)
	2	3 (12%)
Levels	L4-L5	11 (44%)
	L5-S1	11(44%)
	L3-L4-L5	1 (4%)
	L4-L5-S1	2 (8%)
Surgical complications	Incidental durotomy	3 (12%)
Medical complications	Fever	1 (4%)
Postoperative length of hospital stay (days)		4 [3, 4]*
Cage migration		0 (0%)
Screw malposition		0 (0%)

Note: *Continuous variables that do not follow a normal distribution are presented as median [first, third quantiles].

The mean OD-HA increased after surgery to 1.0° ± 2.6°, but this was not statistically significant ($p = 0.093$). There was no change in the mean SVA (4.1 ± 28.9 mm; $p = 0.527$) or PT (−0.1° ± 5.1°; $p = 0.928$) (►**Table 4**) after the intervention.

Most patients ($n = 20$) experienced an increase in LL after surgery, with a mean of 1.9° ± 5.7°, which was not statistically significant ($p = 0.101$) (►**Supplementary Table S2** (online only)). The PI-LL was the only parameter that revealed a statistically significant result in the comparison between M0 and M6, showing a decrease of −2.4° ± 5.7° ($p = 0.045$) (►**Table 4**).

Interestingly, the analysis of the spinopelvic parameters in M0 and M6 for the subgroup of patients with stenosis and spondylolisthesis ($n = 17$), showed a statistical significance for PI-LL mismatch (−4.1 ± 5.7, $p = 0.009$). Moreover, the LL and OD-HA showed a higher mean increase after surgery (3.2° ± 4.9° and 1.4° ± 2.3° respectively), with statistical significance ($p = 0.017$ and $p = 0.036$ respectively) (►**Supplementary Table S2**) (online only).

Analysis of the Clinical and Functional Outcomes

The detailed M0 and M6 clinical and functional outcomes are also demonstrated in ►**Supplementary Table S1** (online only). The mean percentual ODI improvement between M0 and M6 was of 63.6% ± 32.1%, which corresponds to a mean score improvement of 35.6 ± 18.1 ($p < 0.001$) (►**Table 5**). Most patients (64%) presented an M6 ODI of 0% to 20%, which corresponds to minimal disability (►**Fig. 2c**). Moreover, low-back and leg pain showed a statistically significant improvement after surgery ($p < 0.001$). At baseline (M0) the VAS scores for low-back and leg pain were similar, of 7.4 ± 1.8 and 7.8 ± 2.1 respectively. The back pain among 28% of patients completely disappeared, and 24% of the patients presented residual pain (VAS score of 1 or 2) (►**Fig. 2a**). Leg pain showed a more prominent improvement, and was completely absent in 68% the of patients (►**Fig. 2b**).

There were no significant differences in the clinical and functional outcomes in terms of gender (male/female), age (cut-off of 55 years), ASA score, or the presence of depression ($p > 0.05$). Regarding BMI, obese patients (BMI ≥ 30 Kg/m^2) had higher postoperative ODI scores than non-obsese patients (27.5 ± 20.5 versus 13.3 ± 10.2 respectively; $p = 0.041$) (►**Table 6**). The smoking status was not analyzed because almost all patients who were smokers at the time of surgery underwent smoking cessation postoperatively.

Patients with both central and foraminal stenosis displayed a higher mean M6 ODI score when compared with patients with only central or foraminal stenosis (40.8 ± 17.2 versus 16.7 ± 15.9 and 18.0 ± 13.1 respectively; $p = 0.037$) (►**Table 6**). No differences were observed regarding back or leg pain. Patients with stenosis and concomitant spondylolisthesis, when compared with patients without

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Table 4 Preoperative (M0) and postoperative (M6) spinopelvic parameters

Spinopelvic parameter	N	Mean ± standard deviation (range)	Paired *t*-test
SVA (mm)			
M0	21	−9.7 ± 30.4 (−78.0 to 47.5)	$p = 0.527$
M6		−5.6 ± 22.1 (−41.0 to 40.0)	
ΔM6-M0		4.1 ± 28.9 (−63.5 to 62.0)	
OD-HA (degrees)			
M0	22	−4.2 ± 3.3 (−11.0 to 1.1)	$p = 0.093$
M6		−3.3 ± 2.0 (−6.6 to 0.3)	
ΔM6-M0		1.0 ± 2.6 (−3.0 to 7.2)	
PT (degrees)			
M0	25	17.1 ± 7.9 (1.0 to 33.0)	$p = 0.928$
M6		17.2 ± 6.3 (4.5 to 27.2)	
ΔM6-M0		−0.1 ± 5.1 (−9.2 to 10.0)	
PI-LL (degrees)			
M0	25	−5.6 ± 7.2 (−16.3 to 6.0)	***p* = 0.045** (t = −2.120; d = −0.424*)
M6		−8.1 ± 7.0 (−20.0 to 3.7)	
ΔM6-M0		−2.4 ± 5.7 (−18.0 to 16.5)	

Abbreviations: ΔM6-M0, variation between the preoperative (M0) and postoperative (M6) periods; OD-HA, odontoid hip axis angle; PI-LL, pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis. Note: *The effect size measure for *t*-tests was calculated using the Cohen's D.

spondylolisthesis, showed higher levels of leg pain at M6 (2.1 ± 2.8 versus 0.0 ± 0.0 respectively; $p = 0.008$), resulting in a lower global improvement in leg pain (5.6 ± 3.3 versus 8.1 ± 1.6 respectively; $p = 0.021$).

Patients submitted to two-level fusion presented higher ODI scores at M6 than those submitted to one-level fusion, which was statistically significant (43.3 ± 25.3 versus 17.6 ± 14.5 respectively; $p = 0.014$) (►**Table 6**). Individuals submitted to osteotomy had lower levels of leg pain at M6 compared to those who were not (0.1 ± 0.3 versus 2.1 ± 2.8 respectively; $p = 0.014$), which reflected in a higher global improvement in leg pain (8.4 ± 1.5 versus 5.3 ± 3.2 respectively; $p = 0.003$).

The Relationship between Spinopelvic Parameters and Clinical Outcomes

Considering all the patients, the PI-LL was the only spinopelvic parameter that significantly changed between M0 and M6. Thus, we performed a bivariate analysis regarding this parameter and the clinical and functional outcomes (►**Table 7**). For this, we divided the patients in two subgroups considering the normal range for PI-LL mismatch (that is, ± 10°): patients with PI-LL ± 10° and those who fall outside this range (PI-LL > 10° or < −10°). In our population, all the patients out of the normal range had PI-LL < −10°. Our analysis revealed that patients with PI-LL < −10° at M0 had a higher clinical improvement in the VAS score for low-back pain after surgery than patients with a PI-LL ± 10° (6.8 ± 2.1 *versus* 3.6 ± 3.2 respectively; $p = 0.030$). No differences were observed between patients with PI-LL < −10° or PI-LL ± 10° at M0 and M6 for the ODI or VAS scores for leg pain.

Table 5 Analysis of the clinical and functional outcomes

	Mean ± standard deviation (range)	*t*-test		
		p-value	Independent-samples *t*-Test	Effect size[a]
VAS – low-back pain				
M0	7.4 ± 1.8 (1 to 10)	< **0.001**	t = 6.678	d = 1.336
M6	3.1 ± 3.0 (0 to 9)			
Improvement	4.4 ± 3.3 (−1 to 9)			
VAS – leg pain				
M0	7.8 ± 2.1 (1 to 10)	< **0.001**	t = 10.398	d = 2.080
M6	1.4 ± 2.5 (0 to 8)			
Improvement	6.4 ± 3.1 (1 to 10)			
ODI				
M0	56.3 ± 13.7 (34.0 to 82.0)	< **0.001**	t = 9.849	d = 1.970
M6	20.7 ± 17.6 (0 to 70)			
Improvement	35.6 ± 18.1 (−22 to 62)			
% Improvement	63,6% ± 32.1% (−50% to 100%)			

Abbreviations: M0, preoperative period; M6, six months postoperatively; ODI, Oswestry Disability Index; VAS, Visual Analogue Scale.
Note: [a]The effect size measure was calculated using the Cohen D.

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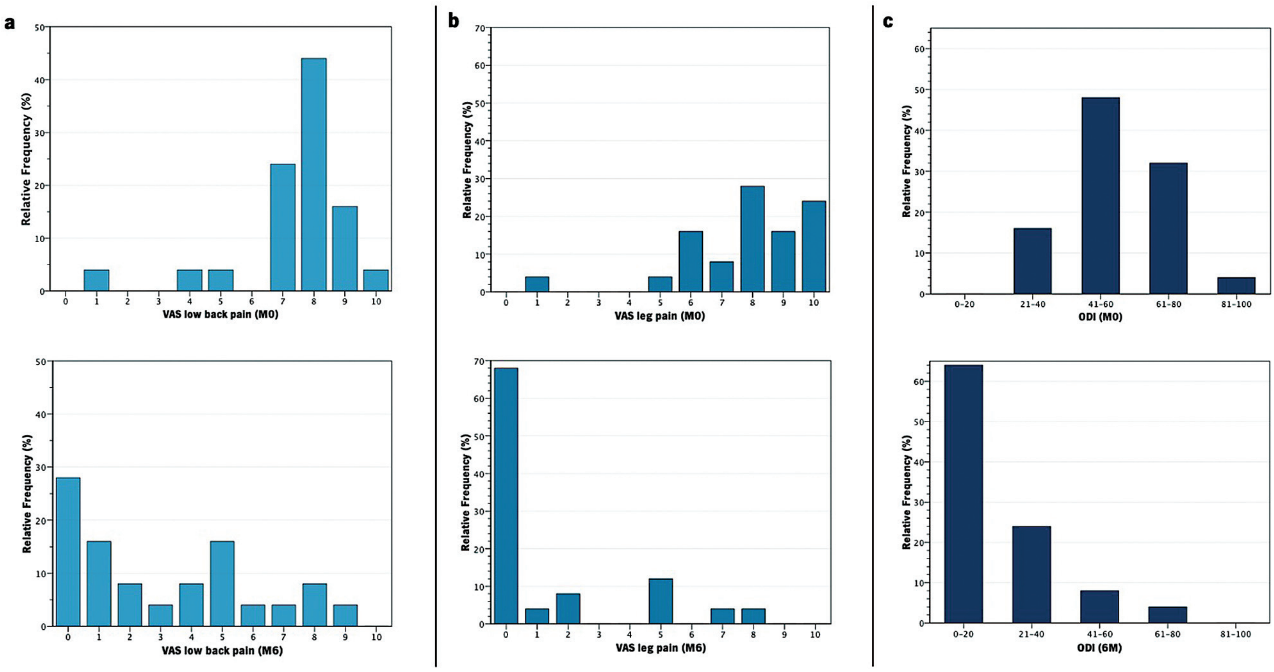

Fig. 2 Graphical representation of the preoperative (M0) and postoperative (M6) clinical and functional outcomes: a) VAS low-back pain; b) VAS leg pain; and c) ODI.

A correlation analysis was performed to assess the relative influence of the PI-LL on the clinical and functional outcomes before and after surgery, as well as on the overall improvement (►**Table 8**). There was a statistically significant moderate correlation between preoperative PI-LL $< -10°$ and improvement in low-back pain ($r_b = 0.435$; $p = 0.030$). No correlation was found regarding the clinical and functional outcomes and other radiological parameters at M0 and M6.

Discussion

In the present study, most patients benefited from surgical intervention, with a mean improvement in ODI scores of 63.6%. They also reported absence of or decrease in pain after surgery. The positive effect of TLIF surgery in pain control and improvement in quality of life is also supported by other studies.[17]

Regarding variables related to patient characteristics, only BMI $\geq$ 30 Kg/m^2 influenced the functional outcome, as obese patients had higher degree of disability at M6. Obesity has been linked with low-back pain and to worse quality of life and surgical outcomes after lumbar fusion surgery.[18] However, some studies have reported an absence of correlation;[19] thus, the specific effect of obesity on patient outcomes is still unclear. Recently, Duan et al.[20] reported that BMI can be a risk factor for adjacent segment pathology (ASP) after TLIF in patients who present changes in spinopelvic parameters, mainly PI-LL > 10°.

Patients who, in addition to spinal stenosis, also had spondylolisthesis, had lower levels of improvement in leg pain after surgery in comparison with patients without spondylolisthesis. However, no differences were verified regarding ODI scores or back pain. This discrepancy can be due to the short postoperative follow-up. Försth et al.[21] concluded that the clinical outcomes in two years of follow-up in patients who had lumbar spinal stenosis, with or without concomitant degenerative spondylolisthesis, were not better than those of patients only submitted to decompression surgery. Better surgical outcomes have been reported for one-level fusion than two-level fusion,[22] which is similar to our results.

Previous studies[8,23,24] have highlighted the influence of spinopelvic parameters, mainly PT and PI-LL, in postoperative residual symptoms. Preoperative loss of LL, assessed by PI-LL > 10°, strongly correlates with disability and loss of quality of life in patients with spinal deformities.[25,26] Accordingly, postoperative PI-LL < 10° seems to be the ideal value for spinopelvic alignment that correlates with reduced pain and disability.[8,27,28] Traditionally, PI-LL < 10° is considered a parameter that needs special attention on the part of surgeons in the planning of corrective surgeries involving long-segment fusions to acquire a suitable LL that achieves a good spinopelvic alignment. However, recent reports[19] revealed that, for some patients and pathologies, higher PI-LL values might be required to reach better outcomes. For example, PI-LL between 10° and 20° seems to be adequate in long-segment fusions in patients with scoliosis.[29] A higher PT, decrease in LL, and PI-LL > 10° have also been associated with postoperative pain in short-segment fusion surgeries.[12,23,30] In our cohort, we observed a significant PI-LL decrease, a trend in LL increase, and no changes in PT when we measured these parameters at M0 and at M6 (►**Table 4** and ►**Supplementary Table S2**) (online only). At M0, most individuals had PI-LL ± 10°, and the ones who did

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Table 6 Bivariate analysis regarding the clinical (VAS) and functional (ODI) outcomes and patient characteristics, diagnosis, and surgery aspects

	ODI			VAS low-back pain			VAS leg pain		
	M0	M6	Imp.	M0	M6	Imp.	M0	M6	Imp.
Patient characteristics									
Gender (M/F)	*	*	*	*	*	*	*	*	*
Age (≥ 55 years)	*	*	*	*	*	*	*	*	*
BMI (≥ 30 Kgm^2)	*	$p = 0.041$ (t = 2.204; d = 0.860)	*	*	*	*	*	*	*
ASA score	*	*	*	*	*	*	*	*	*
Depression (no/yes)	*	*	*	*	*	*	*	*	*
Diagnosis									
Stenosis (F/C/CF)		$p = 0.037$ (F = 3.827)							
Spondylolisthesis (no/yes)	*	*	*	*	*	*	*	$p = 0.008$ (t = −3.038; d = −0.883)	$p = 0.021$ (t = 2.489; d =0.847)
- Degenerative/Isthmic	*	*	*	*	*	*	*	*	*
- Grade (½)	*	*	*	*	*	*	*	*	*
Surgery									
Levels (½)	*	$p = 0.014$ (t = −2.657; d = −1.635)	*	*	*	*	*	*	*
Osteotomy	*	*	*	*	*	*	*	$p = 0.014$ (t = 2.772; d = 0.865)	$p = 0.003$ (t = −3.300; d = −1.140)
Surgical complications									
- Incidental durotomy (no/yes)	*	*	*	*	*	*	*	*	*
Medical complications									
- Fever (no/yes)	*	*	*	*	*	*	*	*	*

Abbreviations: ASA, American Society of Anesthesiologists physical status classification; BMI, Body Mass Index; C, central; CF, central and foraminal; F, female; F, foraminal; Imp., improvement; M, male; M0, preoperative period; M6, six months postoperatively; ODI, Oswestry Disability Index; VAS, Visual Analogue Scale.
Notes: The homogeneity in the variances was assessed by Levene test. t, test statistics for independent-samples *t*-test; F, test statistics for one-way analyss of variance; d, Cohen D; η^2, Eta-squared. *p-value > 0.05.

Table 7 Bivariate analysis regarding PI-LL and the clinical (VAS) and functional (ODI) outcomes

PI-LL (±10° versus < −10°)	ODI			VAS low-back pain			VAS leg pain		
	M0	M6	Δ	M0	M6	Δ	M0	M6	Δ
M0	*	*	*	*	*	$p = 0.030$ (t = 2.314; d = 1.084)	*	*	*
M6	*	*	*	*	*	*	*	*	*

Abbreviations: M0, preoperative period; M6, six months postoperatively; ODI, Oswestry Disability Index; PI-LL, pelvic incidence minus lumbar lordosis; VAS, Visual Analogue Scale.
Notes: The homogeneity in the variances was assessed by the Levene test. t: test statistics for independent-samples *t*-test; d, Cohen D. *p-value > 0.05.

not meet this criterium had PI-LL < −10°. At M6, a decrease in patients with PI-LL ± 10° and an increase in patients with PI-LL < −10° were verified in relation with the LL increase. No patients with PI-LL > 10° were identified in the pre- and postoperative assessments.

Aoki et al.[23] were the first to report that postoperative PI-LL > 10° was associated with residual postoperative low-back and leg pain (assessed by the VAS score) in patients who underwent short-segment TLIF. No significant differences regarding disability, assessed by the ODI, were

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Table 8 Correlation of the PI-LL with clinical (VAS) and functional (ODI) outcomes

	ODI			VAS low back pain			VAS leg pain		
	M0	M6	Imp.	M0	M6	Imp.	M0	M6	Imp.
PI-LL $< -10°$									
M0	0.087	−0.223	0.283	0.176	−0.371	**0.435***	0.136	−0.285	0.320
M6	0.208	−0.015	0.172	0.032	−0.165	0.167	0.233	−0.026	0.177
PI-LL (degrees)									
M0	−0.087	0.084	−0.148	−0.259	0.158	−0.288	−0.103	0.329	−0.333
M6	−0.184	0.033	−0.172	−0.253	0.220	−0.341	−0.262	0.141	−0.288
ΔM6-M0	−0.108	−0.068	−0.016	0.029	0.061	−0.039	−0.179	−0.250	0.080

Abbreviations: Imp., improvement; M0, preoperative period; M6, six months postoperatively; ODI, Oswestry Disability Index; PI-LL, pelvic incidence minus lumbar lordosis; VAS, Visual Analogue Scale.
Notes: The values on the table correspond to correlation coefficients (r). $^*p < 0.05$.

observed between patients with PI-LL $\leq 10°$ and PI-LL $> 10°$, and no correlation was found between PI-LL and the ODI score postoeratively.[23] Recently, Divi et al.[31] concluded that, in a cohort of 306 patients with lumbar degenerative disease submitted to one- or two-level lumbar fusion and a mean follow-up of 13 months, the surgery outcomes (ODI and VAS scores for back and leg pain) were similar in patients with PI-LL$\leq$ 10° and $>10°$. In the present study, we evaluated the association of PI-LL $\pm 10°$ and PI-LL $< -10°$ with the surgical outcomes. As reported by other authors,[23,31] no correlation was found between PI-LL and the postoperative outcomes (►**Table 8**). The results of the present study showed that the improvement in pain and disability does not seem to be related to the change in spinopelvic parameters after surgery. Similar results were obtained in patients with a low grade of spondylolisthesis undergoing TLIF.[32]

We also analyzed the correlation between preoperative spinopelvic parameters and the outcomes (►**Table 8**). Interestingly, our results suggest that PI-LL $< -10°$ may be a predictor for a greater postoperative improvement in leg pain, bringing forth the notion that these patients might be good candidates for TLIF.

The short postoperative follow-up is one of the limitations of the present study. First, we were unable to document the rate of fusion. Second, it is important to analyze if any variable is related to the occurrence of ASP. Some studies[25,33,34] have reported that preoperative global sagittal misalignment and lower LL and PI-LL $> 10°$ pre- and postoperatively resulted in increased load on adjacent segments, predisposing to ASP, which can be analyzed after longer follow-ups. Nevertheless, the observation that preoperative PI-LL $< -10°$ is associated with higher improvement in surgical outcome lead us to believe that our results are reliable and provide a new point of view in the field of short-segment interbody lumbar fusion for the treatment of patients with lumbar spinal stenosis.

The present study shows that, in patients with spinal stenosis with or without concomitant spondylolisthesis, PI-LL$< -10°$ can be a predictor of low back pain improvement after TLIF surgery. Moreover, the global surgery improvement seems to be unrelated to the change in spinopelvic parameters change after surgery. We found that patients with BMI $> 30Kg/m^2$, concomitant spondylolisthesis, absence of osteotomy, and two-level fusion TLIF had lower levels of improvement in surgical outcomes, but no correlation with spinopelvic parameters was observed.

The results of the present study highlight the importance of preoperative planning, first, due to the relevance of spinal sagittal alignment parameters even in short-segment interbody fusion, and second, to identify patients that can benefit more from short-segment lumbar fusion to treat stenosis with or without spondylolisthesis.

Data Availability

The authors declare that all relevant data supporting the findings of the present study are either provided in the Article and Supplementary files or available from the authors upon request.

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Conflict of Interests

The authors have no conflict of interests to declare.

Ethical Standards

The present study was approved by the appropriate local ethics committee. Informed consent, after the description of all the procedures and goals of this research protocol, was obtained before any data collection.

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