http://dx.doi.org/10.1590/S1808-185120242302288424


# MORPHOLOGIC CHANGES OF LUMBAR FORAMEN AND SEGMENTAL LORDOSIS RELATED TO CAGE POSITION IN TRANSFORAMINAL LUMBAR INTERBODY FUSION

## *TLIF- INFLUÊNCIA DA POSIÇÃO DO ESPAÇADOR INTERSOMÁTICO NA LORDOSE SEGMENTAR E ALTURA DO FORAME VERTEBRAL*

## *INFLUENCIA DE LA POSICIÓN DEL ESPACIADOR INTERSOMÁTICO EN LORDOSE SEGMENTAR Y LA ALTURA DEL FORAME VERTEBRAL EN ARTRODESE LOMBAR INTERSOMÁTICO TRANSFORAMINAL*

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## ABSTRACT

Objectives: To evaluate the influence of the positioning of cages on segmental lumbar lordosis and height of the intervertebral foramen when performing transforaminal interbody fusion. Method: cages of 8, 10 and 12 mm were inserted into the disc spaces of the L3-L4, L4-L5 and L5-S1 segments of three human cadavers. Cages were positioned in the anterior, middle and posterior part of the disc space. The transforaminal interbody fusion technique was performed using: unilateral facetectomy, bilateral facetectomy and facetectomy with resection of the adjacent lamina, spinous process and yellow ligament (posterior column osteotomy). The lordosis of the lumbar segment and the height of the intervertebral foramen were measured before and after placement of the cages. Results: The placement of cages in the anterior and middle portion of the disc space produced an increase in segmental lordosis and placement in the posterior portion reduced segmental lordosis. The height of the intervertebral foramen increased with the placement of cages in the posterior portion and a reduction in height with the placement of the interbody spacer in the anterior and middle portion of the disc space. Conclusion: The positioning of the interbody spacer in transforaminal interbody arthrodesis influences segmental lumbar lordosis and the height of the intervertebral foramen. ***Level of Evidence III; Experimental study.***

**Keywords:** Spine fusion; spine; Lumbosacral Region.

## *RESUMO*

*Objetivos: Avaliar a influência do posicionamento dos espaçadores intersomáticos sobre a lordose lombar segmentar e altura do forame intervertebral na realização da artrodese intersomática transforaminal. Métodos: espaçadores intersomáticos de 8, 10 e 12 mm foram inseridos nos espaços discais dos segmentos L3-L4, L4-L5 e L5-S1 de três cadáveres humanos. Os espaçadores foram posicionados na parte anterior, média e posterior do espaço discal. A técnica da artrodese intersomática transforminal foi realizada por meio da: facetectomia unilateral, facetectomia bilateral e facetectomia com ressecção da  da lâmina adjacente,  processo espinhoso e ligamento amarelo  (osteotomia da coluna posterior). A lordose do segmento lombar e a altura do forame intervertebral foram mensurados antes e após a colocação dos espaçadores interespinhosos. Resultados:A colocação dos espaçadores intersomáticos na porção anterior e média do espaço discal produziu aumento da lordose segmentar e a colocação na porção posterior reduziu a lordose segmentar. A altura do forame intervertebral apresentou aumento com a colocação do espaçador na porção posterior e redução da sua altura com o posicionamento do espaçador intersomático na porção anterior e média do espaço discal. Conclusão: o posicionamento do espaçador intersomático na artrodese intersomática transforaminal influencia a lordose lombar segmentar e a altura do forame intervertebral.* ***Nível de evidência III; Estudo experimental.***

***Descritores:*** *Fusão Vertebral; Coluna Vertebral, Região Lombosacral.*

## *RESUMEN*

Objetivos: Evaluar la influencia del posicionamiento de los espaciadores intersomáticos sobre la lordosis lumbar segmentaria y la altura del agujero intervertebral al realizar artrodesis intersomática transforaminal. Métodos: Se insertaron espaciadores intersomáticos de 8, 10 y 12 mm en los espacios discales de los segmentos L3-L4, L4-L5 y L5-S1 de tres cadáveres humanos. Los espaciadores se colocaron en la parte anterior, media y posterior del espacio discal. La técnica de artrodesis intersomática transformacional se realizó mediante: facetectomía unilateral, facetectomía bilateral y facetectomía con resección de la lámina adyacente, apófisis espinosa y ligamento amarillo (osteotomía de la columna posterior). Se midieron la lordosis del segmento lumbar y la altura del agujero intervertebral antes y después

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Received on 07/11/2024 accepted on 07/12/2024
Reviewed by: Marcelo Wajchenberg

de la colocación de los espaciadores interespinosos.Resultados: La colocación de espaciadores intersomáticos en la porción anterior y media del espacio discal produjo un aumento de la lordosis segmentaria y la colocación en la porción posterior redujo la lordosis segmentaria. La altura del agujero intervertebral aumentó con la colocación del espaciador en la porción posterior y una reducción de la altura con la colocación del espaciador intersomático en la porción anterior y media del espacio discal. Conclusion: La posición del espaciador intersomático en la artrodesis intersomática transforaminal influye en la lordosis lumbar segmentaria y en la altura del agujero intervertebral. ***Nivel de Evidencia III; Estudio experimental.***

***Descriptores:*** *Fusión Vertebral; Columna Vertebral; Región Lumbosacra.*

## INTRODUCTION

Lumbar interbody arthrodesis has been performed to provide stability to the vertebral segment, achieve indirect decompression of neural structures, and maintain or correct sagittal imbalance.[1,2] Among the techniques used for lumbar interbody arthrodesis, transforaminal interbody fusion (TLIF) stands out. The transforaminal interbody fusion (TLIF) described by Harms[3] has been widely used for the treatment of degenerative diseases of the lumbar spine.[2,4] The lordosis of the lumbar segment should be restored during the TLIF procedure and is related to different factors, with vertebral spacers being prominent.[5,6] The geometry of the spacers, their positioning in the disc space (anterior, middle, posterior), and their dimensions (height, length) are parameters that influence the reconstruction of segmental lordosis (SL) and the height of the vertebral foramen in the fusion.[7] The importance of the vertebral foramen is related to its decompression and the occurrence of contralateral foramen stenosis, which occurs in 5.9% of patients undergoing transforaminal fusion (TLIF).[8-10]

The objective of the study was to evaluate the influence of the positioning of the intervertebral spacer on segmental lordosis (SL) and the height of the intervertebral foramen (HIF) in the lumbar spine segments of human cadavers. The hypothesis of the study was that segmental lumbar lordosis and the height of the vertebral foramen are influenced by the positioning of the interbody spacer used in the transforaminal lumbar interbody fusion (TLIF) technique. Although there are clinical studies on the influence of spacer positioning on these variables, there are few studies using cadaver specimens, which allow for greater control of the variables.

## MATERIAL AND METHODS

The study was approved by the Research Ethics Committee of the Ribeirão Preto Medical School at the University of São Paulo (CAE:78956323.7.0000.5440). Three segments (L3-L4, L4-L5, and L5-S1) of the lumbar spine from two adult male cadavers were used. The anatomical integrity of the vertebral segments selected for the study was verified through simple X-rays in AP and lateral views. The segments of the lumbar spine used in the study showed no macroscopic signs of traumatic injury, previous surgery, disease, deformity, or ankylosis.

The PEEK (polyetheretherketone) spacers model Fusimax TLP® (MDT), with 8 mm width, 29 mm length, and without angulation were used in the experiments, simulating their application in transforaminal interbody fusion (TLIF). The height of the intersomatic spacer was selected according to the measurement of the height of the intervertebral space evaluated in the radiographs. 8mm spacers were used in the L3-L4 space, and 10 and 12 mm spacers in the L4-L5 and L5-S1 spaces.

The technique of transforaminal interbody fusion was performed on the vertebral segments (L3-S1) and the experimental groups were formed according to the positioning of the spacer in the disc space (anterior, middle, or posterior) (Figure 1), and according to the removal of the posterior vertebral elements: Group A - unilateral removal of the articular facets; Group B - bilateral removal of the articular facets; Group C - bilateral removal of the articular facets with resection of the midline of the adjacent lamina, spinous processes, and yellow ligament. (Figure 2)

Segmental lordosis (SL) and intervertebral foramen height (HIF) were the parameters selected for the study. The SL was evaluated

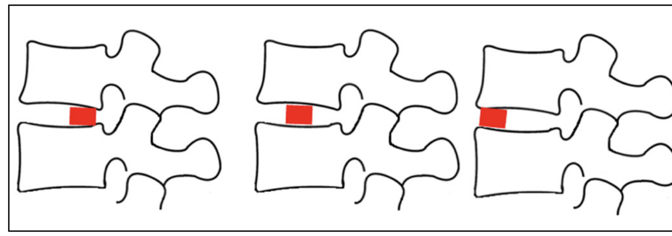

**Figure 1.** Drawing illustrating the positioning of the intervertebral spacer in the disc space (posterior, middle, and anterior).

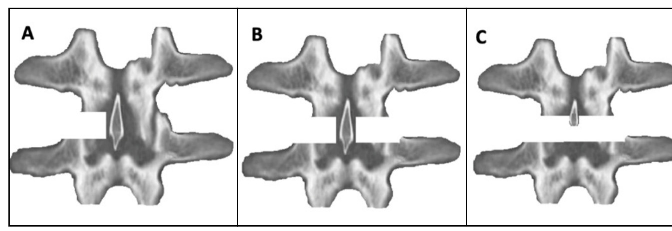


**Figure 2.** Drawing illustrating the removal of posterior vertebral elements according to the experimental group: (A) unilateral facetectomy, (B) bilateral facetectomy, and (C) facetectomy with resection of the adjacent lamina, spinous process, and yellow ligament (posterior column osteotomy).

through the angle, observed in lateral radiographs, formed by the superior and inferior vertebral plates of the disc space in which the spacer was inserted. The HIF was measured on both sides using a digital caliper. The greatest distance between the lower edge of the upper pedicle and the upper edge of the lower vertebral pedicle were the anatomical references used to measure the height of the vertebral foramen.

The measurements were taken with the specimens intact and after the procedure established for each experimental group, which was related to the positioning of the intersomatic spacer (anterior, middle, and posterior) and the removal of the posterior vertebral elements. (Figure 1 and 2)

The statistical study was conducted using descriptive statistics, the Kolmogorov-Smirnov test was used to determine the normality of the sample, and the ANOVA test, followed by the Tukey test, was used to compare the results of the intervertebral disc angulation, disc opening, and vertebral foramen height between the experimental groups. The significance level was set at $p<0.05$.

## RESULTS

The results of the descriptive statistics and SL values in the different experimental groups are illustrated in Tables 1 and 2.

A tendency to increase the SL angulation was observed with the placement of the spacer in the anterior and middle part of the disc space. The posterior positioning of the intervertebral spacer reduced the SL in relation to the control values (before performing the TLIF). The behavior of the trends of the different experimental groups is illustrated in figure 3, and the statistical differences of the SL between the experimental groups in Figure 3 and Table 3.

The positioning of the intervertebral spacer in the anterior and middle part of the disc space showed a tendency to increase SL. The positioning at the back showed a tendency to reduce the angulation.

**Table 1.** Descriptive statistics of the values of the disc opening (lordosis disc space).

| | Control | Aa | Am | Ap | Ba | Bm | Bp | Ca | Cm | Cp |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of values | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Minimum | 7.8 | 9.4 | 9.3 | 7 | 9.7 | 9.3 | 7 | 10.8 | 11.4 | 7.4 |
| Maximum | 10 | 14.8 | 14.3 | 9.8 | 15.1 | 14.4 | 9.9 | 18.4 | 17.8 | 10.2 |
| Range | 2.2 | 5.4 | 5 | 2.8 | 5.4 | 5.1 | 2.9 | 7.6 | 6.4 | 2.8 |
| Mean | 8.667 | 11.03 | 11.25 | 7.833 | 11.37 | 11.42 | 7.983 | 13.97 | 13.12 | 8.417 |
| Std. Deviation | 0.9352 | 2.025 | 1.846 | 1.075 | 2.015 | 1.828 | 1.105 | 3.312 | 2.458 | 1.048 |
| Std. Error of Mean | 0.3818 | 0.8265 | 0.7535 | 0.4387 | 0.8225 | 0.7463 | 0.4512 | 1.352 | 1.003 | 0.4277 |
| Lower 95% CI of mean | 7.685 | 8.909 | 9.313 | 6.706 | 9.252 | 9.498 | 6.823 | 10.49 | 10.54 | 7.317 |
| Upper 95% CI of mean | 9.648 | 13.16 | 13.19 | 8.961 | 13.48 | 13.34 | 9.143 | 17.44 | 15.7 | 9.516 |
| Coefficient of variation | 10.79% | 18.35% | 16.41% | 13.72% | 17.72% | 16.01% | 13.84% | 23.72% | 18.74% | 12.45% |

A - unilateral facetectomy B - bilateral facetectomy C - bilateral facetectomy + lamina A - Anterior spacer b - middle portion spacer c - posterior spacer.

**Table 2.** Results of disc opening (lordosis of the disc space) in degrees in different experimental groups.

| Segment | Specimen | Control | Aa | Am | Ap | Ba | Bm | Bp | Ca | Cm | Cp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L3-L4 | 1 | 8 | 9.7 | 9.9 | 7.1 | 9.9 | 10.4 | 7.2 | 10.8 | 12.3 | 7.4 |
| L3-L4 | 2 | 9.4 | 9.8 | 10.9 | 8.2 | 10.3 | 10.9 | 8.6 | 11.3 | 11.4 | 8.7 |
| Average | | 8.7 | 9.75 | 10.4 | 7.65 | 10.1 | 10.65 | 7.9 | 11.05 | 11.85 | 8.05 |
| DP | | 0.99 | 0.07 | 0.71 | 0.78 | 0.28 | 0.35 | 0.99 | 0.35 | 0.64 | 0.92 |
| L4-L5 | 1 | 7.8 | 9.4 | 9.3 | 7 | 9.7 | 9.3 | 7 | 12.3 | 12 | 7.8 |
| L4-L5 | 2 | 9 | 11.6 | 12.5 | 7.8 | 11.9 | 12.7 | 7.9 | 17.8 | 13.8 | 8.8 |
| Average | | 8.4 | 10.5 | 10.9 | 7.4 | 10.8 | 11 | 7.45 | 15.05 | 12.9 | 8.3 |
| DP | | 0.85 | 1.56 | 2.26 | 0.57 | 1.56 | 2.40 | 0.64 | 3.89 | 1.27 | 0.71 |
| L5-S1 | 1 | 10 | 14.8 | 14.3 | 9.8 | 15.1 | 14.4 | 9.9 | 18.4 | 17.8 | 10.2 |
| L5-S1 | 2 | 7.8 | 10.9 | 10.6 | 7.1 | 11.3 | 10.8 | 7.3 | 13.2 | 11.4 | 7.6 |
| Average | | 8.9 | 12.85 | 12.45 | 8.45 | 13.2 | 12.6 | 8.6 | 15.8 | 14.6 | 8.9 |
| DP | | 1.56 | 2.76 | 2.62 | 1.91 | 2.69 | 2.55 | 1.84 | 3.68 | 4.53 | 1.84 |

A- unilateral facetectomy B- bilateral facetectomy C- bilateral facetectomy + lamina. A - anterior spacer b- middle portion spacer c- posterior spacer.

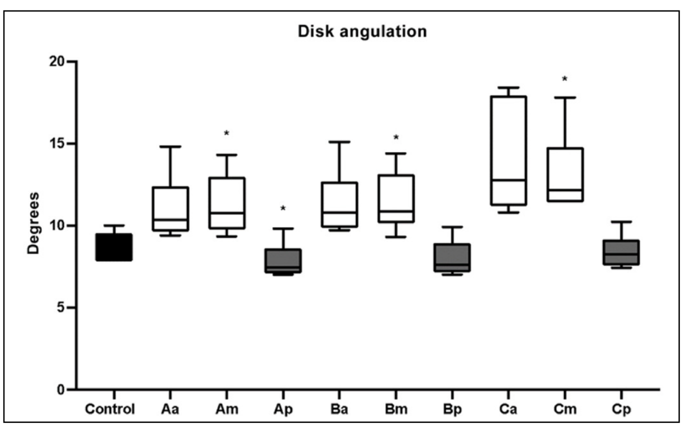


**Figure 3.** Graph illustrating the variation of segmental lordosis in different experimental groups. A - unilateral removal of the articular facets; B - bilateral removal of the articular facets; and C - bilateral removal of the articular facets with resection of the adjacent lamina midline, spinous processes, and yellow ligament. The lowercase letters A, M, and P indicate respectively the positioning in the anterior, middle, and posterior part of the disc space. The asterisk (*) indicates a statistical difference compared to the control group (ANOVA test, followed by Tukey's test p<0.05).

This trend was observed in all studied vertebral segments (L3-L4, L4-L5, and L5-S1) and in all techniques of transforaminal arthrodesis (A, B, and C). (Figure 4)

The HIF values in the control group and related to the positioning of the intersomatic spacer in the experimental groups are illustrated in Tables 4 and 5.

It was observed the trend of reducing the HIF with the positioning of the spacer in the anterior and middle part of the disc space. The positioning of the intersomatic spacer in the posterior part of the disc space showed a tendency to increase the height of the foramen. (Figure 5)

A statistical difference was observed between some isolated experimental groups, evidencing the observed trend. However, the sample size did not allow for precise statistical analysis.

**Table 3.** Table indicating the statistical difference between the values of the intervertebral disc angulation in the experimental groups.

| | Aa | Am | Ap | Ba | Bm | Bp | Ca | Cm | Cp |
|---|---|---|---|---|---|---|---|---|---|
| **Control** | **ns** | ***** | ***** | **ns** | ***** | **ns** | **ns** | ***** | **ns** |
| Aa | | ns | * | ** | ns | * | ns | * | * |
| Am | | | ** | ns | ns | ** | ns | ns | * |
| Ap | | | | * | ** | ns | * | ** | * |
| Ba | | | | | ns | * | ns | ns | * |
| Bm | | | | | | ** | ns | ns | * |
| Bp | | | | | | | * | ** | ns |
| Ca | | | | | | | | ns | * |
| Cm | | | | | | | | | * |

The asterisk (*) indicates statistical difference (ANOVA test, followed by Tukey's test p<0.05).

The results showed the tendency of the intersomatic spacer located in the anterior and middle portion of the intervertebral disc to increase the and reduce the HIF. The posterior positioning of the intersomatic spacer showed a tendency to reduce the angulation of the intervertebral disc and increase the height of the vertebral foramen. These trends were similar across all experimental groups that simulated TLIF variations.

## DISCUSSION

The hypothesis presented in the study was confirmed and the positioning of the intersomatic spacers inside the intervertebral disc induced changes in segmental lumbar lordosis and the height of the vertebral foramen.

The preservation or restoration of segmental lordosis is one of the objectives of different interbody fusion techniques (ALIF, PLIF, TLIF, LL) and is associated with clinical outcomes.[11-14] The restoration of segmental lumbar lordosis is multifactorial, and interbody spacers play a prominent role among these factors.[13,15] The positioning, size, angulation, and shape of the spacers influence the restoration of segmental lumbar lordosis.[13]

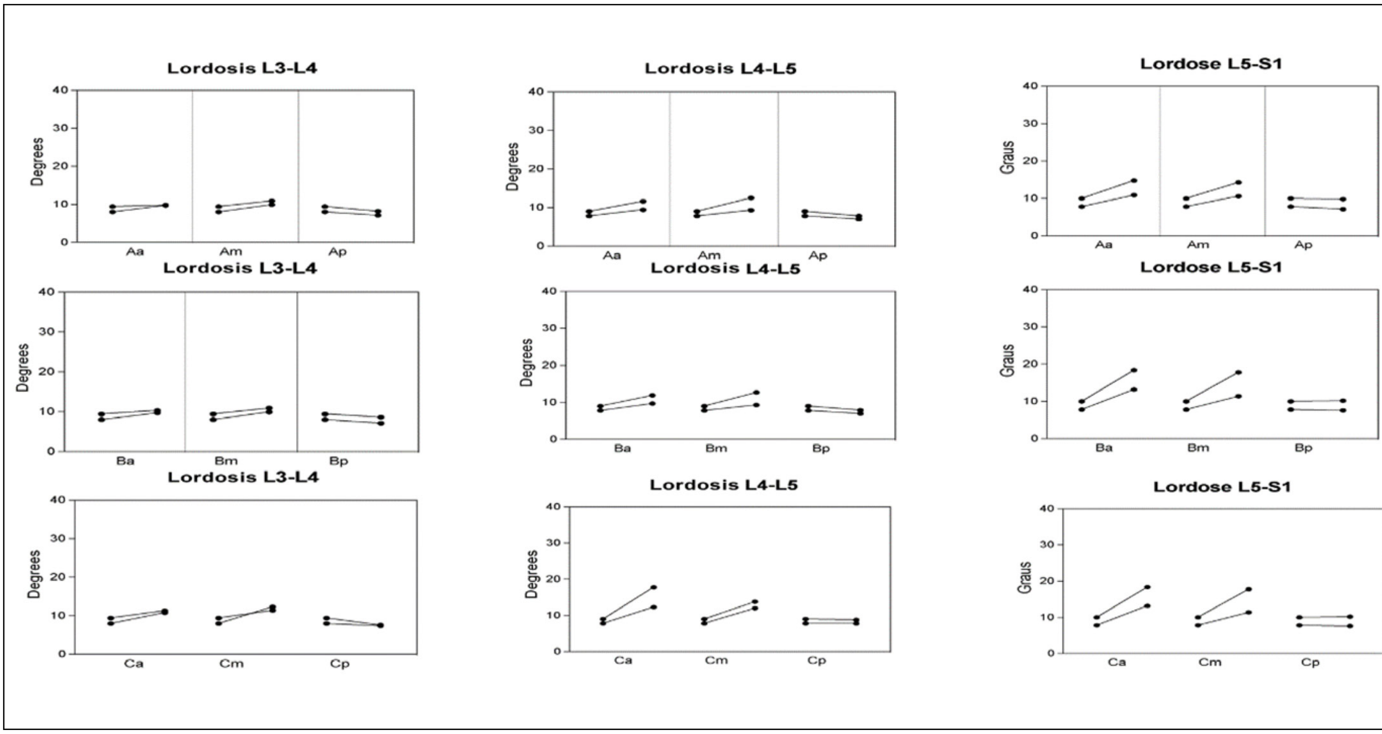


**Figure 4.** Variation of segmental lordosis at levels L3-L4, L4-L5, and L5-S1 in both segments of the lumbar spine. A - Unilateral removal of the articular facets; B - bilateral removal of the articular facets; and C - bilateral removal of the articular facets with resection of the midline of the adjacent lamina, spinous processes, and yellow ligament. The lowercase letters a, m, and p respectively indicate the positioning in the anterior, middle, and posterior part of the disc space.

**Tabela 4.** Measurement values of AFI on the left side (millimeters) in the control group and in the segments with intersomatic spacers.

| Discal space | Control L | Aa L | Am L | Ap L | Ba L | Bm L | Bp L | Ca L | Cm L | Cp L |
|---|---|---|---|---|---|---|---|---|---|---|
| L3-L4 (1) | 21.3 | 19.45 | 19.85 | 22.3 | 19 | 19.55 | 21.6 | 17.4 | 17.6 | 20.45 |
| L3-L4 (2) | 20.4 | 19.6 | 19.9 | 21 | 19.4 | 19.61 | 19.5 | 18.97 | 19.03 | 19.3 |
| L4-L5 (1) | 12.85 | 12.7 | 12.6 | 13.4 | 12 | 12.1 | 13.3 | 11.15 | 10.95 | 13.05 |
| L4-L5 (2) | 19.7 | 18.15 | 18 | 19.98 | 18 | 17.9 | 19.8 | 16.7 | 16.5 | 19.75 |
| L5-S1 (1) | 11.05 | 12.6 | 12.85 | 14.5 | 12.2 | 12.5 | 14.1 | 11.9 | 12.3 | 14 |
| L5-S1 (2) | 13.8 | 14.4 | 14.35 | 15.5 | 14.3 | 14.2 | 15.1 | 13.8 | 14 | 15 |

A - unilateral removal of the articular facets; B - bilateral removal of the articular facets; and C - bilateral removal of the articular facets with resection of the adjacent lamina midline, spinous processes, and yellow ligament. The lowercase letters a, m, and p, respectively, indicate the positioning in the anterior, middle, and posterior parts of the disc space.

**Table 5.** Measurement values of the HIF on the right side (millimeters) in the control group and in the segments with intersomatic spacers.

| Disc space | Control And | Aa L | Am L | Ap L | Ba L | Bm L | Bp L | Ca L | Cm L | Cp L |
|---|---|---|---|---|---|---|---|---|---|---|
| L3-L4 (1) | 21.3 | 19.45 | 19.85 | 22.3 | 19 | 19.55 | 21.6 | 17.4 | 17.6 | 20.45 |
| L3-L4 (2) | 20.4 | 19.6 | 19.9 | 21 | 19.4 | 19.61 | 19.5 | 18.97 | 19.03 | 19.3 |
| L4-L5 (1) | 12.85 | 12.7 | 12.6 | 13.4 | 12 | 12.1 | 13.3 | 11.15 | 10.95 | 13.05 |
| L4-L5 (2) | 19.7 | 18.15 | 18 | 19.98 | 18 | 17.9 | 19.8 | 16.7 | 16.5 | 19.75 |
| L5-S1 (1) | 11.05 | 12.6 | 12.85 | 14.5 | 12.2 | 12.5 | 14.1 | 11.9 | 12.3 | 14 |
| L5-S1 (2) | 13.8 | 14.4 | 14.35 | 15.5 | 14.3 | 14.2 | 15.1 | 13.8 | 14 | 15 |

A - Unilateral removal of the articular facets; B - bilateral removal of the articular facets; and C - bilateral removal of the articular facets with resection of the midline of the adjacent lamina, spinous processes, and yellow ligament. The lowercase letters a, m, and p respectively indicate the positioning in the anterior, middle, and posterior part of the disc space.

The influence of the positioning of intersomatic spacers on segmental lumbar lordosis has been the target of clinical and experimental studies. We observed in our study that the positioning of the intersomatic spacer in the anterior and middle part of the disc space induced an increase in segmental lumbar lordosis, while positioning in the posterior part induced a reduction in segmental lumbar lordosis compared to the initial value used as control. Similar results were observed in a clinical study in patients undergoing lateral interbody fusion.[1] The increase in segmental lumbar lordosis with the anterior positioning of the interbody spacer was observed in clinical and experimental reports.[11,13,16-22] However, no difference was observed in clinical[23,24] or experimental studies,[16,25] highlighting the controversy and heterogeneity of studies on the subject.[23-25] A higher incidence of spacer subsidence was observed in the posterior positioning.[26]

The results observed in the studies conducted on synthetic models and human cadavers showed contradictory results.[27,28] The difference in results could be attributed to the presence of the anterior longitudinal ligament in the vertebrae of cadavers, which shows great resistance to forces that tend to increase the lordosis of the intervertebral space. The influence of the anterior longitudinal ligament on the increase of segmental lumbar lordosis was observed in the association of the ALL release and the use of lateral hyperlordotic spacers.[29]

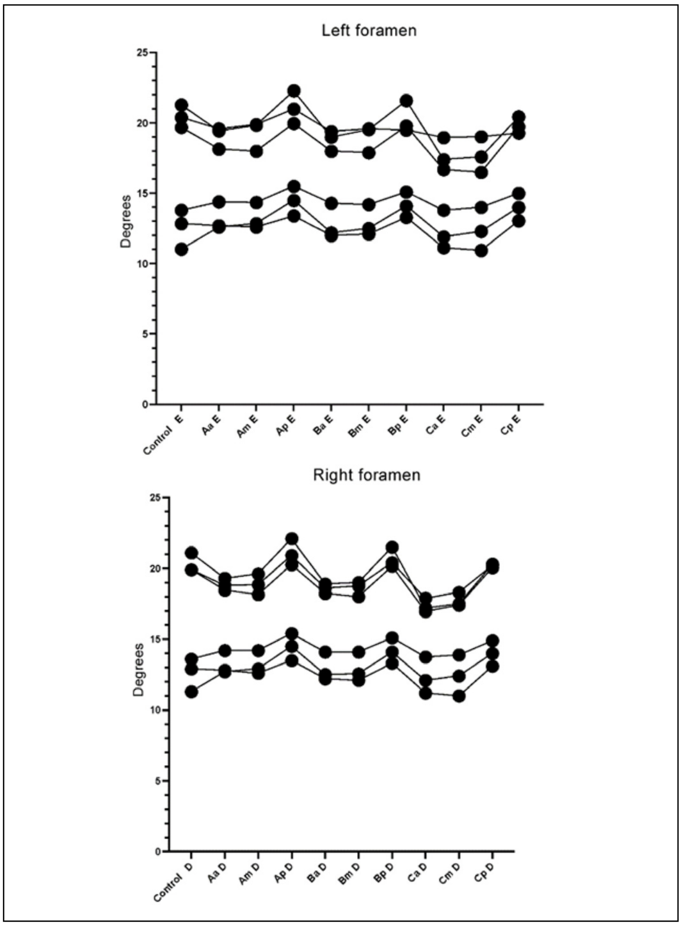


**Figure 5.** Graph illustrating the individual behavior of the height of the vertebral foramen in the segments of the lumbar spine and different experimental groups. A - Unilateral removal of the articular facets; B - bilateral removal of the articular facets; and C - bilateral removal of the articular facets with resection of the adjacent lamina midline, spinous processes, and yellow ligament. The lowercase letters a, m, and p respectively indicate the positioning in the anterior, middle, and posterior part of the disc space.

The original TLIF technique was described by Harms and advocated the placement of spacers in the middle or posterior portion associated with intense filling of the anterior portion with bone graft and mobilization of bone flaps from the upper and lower surfaces of the vertebral plates.[3] We did not observe a statistical difference between the positioning of the interbody spacer in the anterior and middle part of the intervertebral disc, and both showed a tendency to increase the angulation of the intervertebral disc.

The positioning of the spacers in the anterior and middle part of the disc space induced an increase in the angulation of the intervertebral disc, and the reduction was observed with the posterior positioning in all modalities of transforaminal lumbar interbody fusion (TLIF) (unilateral facetectomy, bilateral or resection of the posterior elements). However, the technique and type of spacer used must be considered when interpreting the results of the studies.[13,15]

Interbody spacers are also used to restore disc space height, perform indirect decompression of neural structures, promote arthrodesis, and restore lordosis of the vertebral segment.[13,15,16,20]

The interest in evaluating the height of the vertebral foramen is related to the indirect decompression of nervous structures and the observation of contralateral radiculopathy after MIS-TLIF. Contralateral radiculopathy has been reported in 2-8.5% of patients, caused by nerve root compression within the vertebral foramen.[9,10,30,31] The position of the interbody spacer induces a change in the height of the vertebral foramen, and the posterior positioning of the spacer has been reported in clinical and experimental studies as producing the greatest increase in the height of the vertebral foramen.[30,32] Literature reports[16,26,27,20,28,31,32] are consistent with the results observed in our experiment, in which the posterior positioning of the spacer promoted the greatest increase in the height of the vertebral foramen compared to the anterior and middle positioning within the disc space. The posterior positioning of the spacer in the lateral interbody fusion technique also showed greater decompression of the vertebral foramen.[22] The posterior positioning of the interbody spacer has been associated with spacer subsidence.[26,27]

The result of our experiment on cadavers showed different results from the experiment previously conducted on a lumbar spine model with polyurethane vertebrae and polyethylene intervertebral disc.[28] The difference in results could be attributed to the presence of the anterior longitudinal ligament in the cadaver vertebrae, which presents great resistance to forces that tend to increase the lordosis of the intervertebral space. The influence of the anterior longitudinal ligament on the increase of lordosis in the intervertebral space has been observed in the association of the release of the ALL and the use of hyperlordotic lateral spacers.[29]

The study presents limitations related to the difficulty in obtaining segments of the lumbar spine from cadavers to be used in the study, requiring the use of a small sample and limiting the statistical analysis of the results. All segments of the lumbar spine used in the study (L3-S1) were included in the statistical analysis. Levels with different degrees of lordosis were analyzed together. In clinical trials, the greatest correction of lordosis has been observed in segments with lower angular values.[12,13,17] Despite the small sample size, the experimental study allowed for the control of variables involved in the TLIF technique, enabling the homogenization of the procedure.

The importance of sagittal alignment of the spine, the restoration of lumbar lordosis, and its relationship with good clinical outcomes has been recognized and widely reported in the literature.[1,4,12] The restoration of lordosis of the vertebral segment is multifactorial and the positioning of the spacers stands out and should be valued in the performance of TLIF. The increase in lordosis of the vertebral segment does not depend solely on the characteristics of the spacers.[1,19,27] The presented results can contribute to the practical application of TLIF considering the positioning of the intervertebral spacer within the disc space and its influence on disc angulation and vertebral foramen height. The TLIF technique.

## CONCLUSIONS

The positioning of the interbody spacer in the anterior and middle part of the disc space promoted greater segmental lordosis, and the greatest height of the intervertebral foramen was observed with the posterior positioning of the spacer in the disc space.

All authors declare no potential conflict of interest related to this article.

**CONTRIBUTIONS OF THE AUTHORS:** Each author contributed individually and significantly to the development of this article. TDM: substantial contributions to the study design; data acquisition and interpretation for the study. Final approval of the version of the manuscript to be published; LFT, AMA, VAG, MPD: support in scientific writing for the study and review; HLAD: substantial contributions to the conception of the study; acquisition and interpretation of data for the study. Guidance and final approval of the version of the manuscript to be published.

## REFERENCES


1. Issa TZ, Lee Y, Lambrechts MJ, Tran KS, Trenchfield D, Baker S, et al. The impact of cage positioning on lumbar lordosis and disc space restoration following minimally invasive lateral lumbar interbody fusion. Neurosurg Focus. 2023;54(1):E7.
2. Ferrer A, Demonti H, Fiorillo P. Evaluación de la fusión segmentaria con técnica TLIF con cajas de PEEK en patología degenerativa lumbar: ¿ es la radiografía dinámica útil para el diagnóstico de fusión segmentaria en pacientes tratados?. Coluna/Columna [online]. 2012, v. 11, n. 2 [Accedido 29 Noviembre 2022], pp. 148-150.
3. Harms JG, Jeszenszky D. Die posteriore, lumbale, interkorporelle Fusion in unilateraler transforaminaler Technik. Oper Orthop Traumatol. 1998;10(2):90-102. German.
4. Wasinpongwanich K, Nopsopon T, Pongpirul K. Surgical Treatments for Lumbar Spine Diseases (TLIF vs. Other Surgical Techniques): A Systematic Review and Meta-Analysis. Front Surg. 2022;9:829469.
5. Lazennec JY, Ramaré S, Arafati N, Laudet CG, Gorin M, Roger B, et al. Sagittal alignment in lumbosacral fusion: relations between radiological parameters and pain. Eur Spine J. 2000;9(1):47-55.
6. Kawakami M, Tamaki T, Ando M, Yamada H, Hashizume H, Yoshida M. Lumbar sagittal balance influences the clinical outcome after decompression and posterolateral spinal fusion for degenerative lumbar spondylolisthesis. Spine (Phila Pa 1976). 2002 Jan 1;27(1):59-64.
7. Gödde S, Fritsch E, Dienst M, Kohn D. Influence of cage geometry on sagittal alignment in instrumented posterior lumbar interbody fusion. Spine (Phila Pa 1976). 2003;28(15):1693-9.
8. Jang KM, Park SW, Kim YB, Park YS, Nam TK, Lee YS. Acute Contralateral Radiculopathy after Unilateral Transforaminal Lumbar Interbody Fusion. J Korean Neurosurg Soc. 2015;58(4):350-6.
9. Hunt T, Shen FH, Shaffrey CI, Arlet V. Contralateral radiculopathy after transforaminal lumbar interbody fusion. Eur Spine J. 2007;16 Suppl 3(Suppl 3):311-4.
10. Yang Y, Liu ZY, Zhang LM, Dong JW, Xie PG, Chen RQ, et al. Risk factor of contralateral radiculopathy following microendoscopy-assisted minimally invasive transforaminal lumbar interbody fusion. Eur Spine J. 2018;27(8):1925-1932.
11. Jagannathan J, Sansur CA, Oskouian RJ Jr, Fu KM, Shaffrey CI. Radiographic restoration of lumbar alignment after transforaminal lumbar interbody fusion. Neurosurgery. 2009y;64(5):955-63; discussion 963-4.
12. Rothrock RJ, McNeill IT, Yaeger K, Oermann EK, Cho SK, Caridi JM. Lumbar Lordosis Correction with Interbody Fusion: Systematic Literature Review and Analysis. World Neurosurg. 2018;118:21-31
13. Landham PR, Don AS, Robertson PA. Do position and size matter? An analysis of cage and placement variables for optimum lordosis in PLIF reconstruction. Eur Spine J. 2017;26(11):2843-2850.
14. Liang Y, Shi W, Jiang C, Chen Z, Liu F, Feng Z, Jiang X. Clinical outcomes and sagittal alignment of single-level unilateral instrumented transforaminal lumbar interbody fusion with a 4 to 5-year follow-up. Eur Spine J. 2015;24(11):2560-6.
15. Walter C, Baumgärtner T, Trappe D, Frantz S, Exner L, Mederake M. Influence of Cage Design on Radiological and Clinical Outcomes in Dorsal Lumbar Spinal Fusions: A Comparison of Lordotic and Non-Lordotic Cages. Orthop Surg. 2021;13(3):863-875.
16. Robertson PA, Armstrong WA, Woods DL, Rawlinson JJ. Lordosis Recreation in Transforaminal and Posterior Lumbar Interbody Fusion: A Cadaveric Study of the Influence of Surgical Bone Resection and Cage Angle. Spine (Phila Pa 1976). 2018;43(22):E1350-E1357.
17. Lovecchio FC, Vaishnav AS, Steinhaus ME, Othman YA, Gang CH, Iyer S, et al. Does interbody cage lordosis impact actual segmental lordosis achieved in minimally invasive lumbar spine fusion? Neurosurg Focus. 2020;49(3):E17.
18. Otsuki B, Fujibayashi S, Takemoto M, Kimura H, Shimizu T, Murata K, et al. Analysis of the Factors Affecting Lumbar Segmental Lordosis After Lateral Lumbar Interbody Fusion. Spine (Phila Pa 1976). 2020;45(14):E839-E846.
19. Liu J, Duan P, Mummaneni PV, Xie R, Li B, Dong Y, et al. Does transforaminal lumbar interbody fusion induce lordosis or kyphosis? Radiographic evaluation with a minimum 2-year follow-up. J Neurosurg Spine. 2021;35(4):419-426.
20. Kepler CK, Rihn JA, Radcliff KE, Patel AA, Anderson DG, Vaccaro AR, et al. Restoration of lordosis and disk height after single-level transforaminal lumbar interbody fusion. Orthop Surg. 2012;4(1):15-20.
21. Kim JT, Shin MH, Lee HJ, Choi DY. Restoration of lumbopelvic sagittal alignment and its maintenance following transforaminal lumbar interbody fusion (TLIF): comparison between straight type versus curvilinear type cage. Eur Spine J. 2015;24(11):2588-96.
22. Mahatthanatrakul A, Kotheeranurak V, Lin GX, Hur JW, Chung HJ, Lokanath YK, et al. Do Obliquity and Position of the Oblique Lumbar Interbody Fusion Cage Influence the Degree of Indirect Decompression of Foraminal Stenosis? J Korean Neurosurg Soc. 2022;65(1):74-83.
23. DiMaria S, Karamian BA, Siegel N, Lambrechts MJ, Grewal L, Jeyamohan HR, et al. Does Interbody Cage Lordosis and Position Affect Radiographic Outcomes After Single-level Transforaminal Lumbar Interbody Fusion? Clin Spine Surg. 2022;35(9):E674-E679.
24. Faundez AA, Mehbod AA, Wu C, Wu W, Ploumis A, Transfeldt EE. Position of interbody spacer in transforaminal lumbar interbody fusion: effect on 3-dimensional stability and sagittal lumbar contour. J Spinal Disord Tech. 2008;21(3):175-80.
25. Carlson BB, Saville P, Dowdell J, Goto R, Vaishnav A, Gang CH, et al. Restoration of lumbar lordosis after minimally invasive transforaminal lumbar interbody fusion: a systematic review. Spine J. 2019;19(5):951-958.
26. Amorim-Barbosa T, Pereira C, Catelas D, Rodrigues C, Costa P, Rodrigues-Pinto R, et al. Risk factors for cage subsidence and clinical outcomes after transforaminal and posterior lumbar interbody fusion. Eur J Orthop Surg Traumatol. 2022;32(7):1291-1299.
27. Ding Q, Tang X, Zhang R, Wu H, Liu C. Do Radiographic Results of Transforaminal Lumbar Interbody Fusion Vary with Cage Position in Patients with Degenerative Lumbar Diseases? Orthop Surg. 2022;14(4):730-741.
28. Matos TD, Fleury RBC, Teixeira KO, Romero V, Defino HLA. CHANGES IN THE LUMBAR VERTEBRAL SEGMENT RELATED TO THE CAGE POSITION IN TLIF TECHNIQUE. Acta Ortop Bras. 2020;28(2):92-96.
29. Uribe JS, Smith DA, Dakwar E, Baaj AA, Mundis GM, Turner AW, et al. Lordosis restoration after anterior longitudinal ligament release and placement of lateral hyperlordotic interbody cages during the minimally invasive lateral transpsoas approach: a radiographic study in cadavers. J Neurosurg Spine. 2012;17(5):476-85.
30. Schwender JD, Holly LT, Rouben DP, Foley KT. Minimally invasive transforaminal lumbar interbody fusion (TLIF): technical feasibility and initial results. J Spinal Disord Tech. 2005;18 Suppl:S1-6.
31. Liu J, Duan P, Mummaneni PV, Xie R, Li B, Dong Y, et al. Does transforaminal lumbar interbody fusion induce lordosis or kyphosis? Radiographic evaluation with a minimum 2-year follow-up. J Neurosurg Spine. 2021;35(4):419-426.
32. Iwata T, Miyamoto K, Hioki A, Fushimi K, Ohno T, Shimizu K. Morphologic Changes in Contralateral Lumbar Foramen in Unilateral Cantilever Transforaminal Lumbar Interbody Fusion Using Kidney-type Intervertebral Spacers. J Spinal Disord Tech. 2015;28(5):E270-6.