http://dx.doi.org/10.1590/S1808-185120242302288420

CHANGES OF VERTEBRAL SEGMENT AND FORAMEN WITH ANTERIOR INTERBODY SPACER

ALTERAÇÃO DO SEGMENTO E FORAME VERTEBRAL COM ESPAÇADOR INTERSOMÁTICO ANTERIOR

ALTERACIÓN DEL SEGMENTO VERTEBRAL Y FORAMEN CON ESPACIADOR INTERSOMÁTICO ANTERIOR

THIAGO DANTAS MATOS[1], LUIS FERNANDO TIRAPELLI[2], ALEXANDRE MACHADO ANDRADE[3], VITOR ARAUJO GONÇALVES[1], MATHEUS PIPPA DEFINO[1], HELTON LUIZ APARECIDO DEFINO[1]

1. Universidade de São Paulo, Ribeirão Preto Medical School, Department of Orthopedics and Anesthesiology, São Paulo, SP, Brazil.
2. Universidade de São Paulo, Department of Surgery and Anatomy, São Paulo, SP, Brazil.
3. CDO Clinica Medica, Salvador, BA, Brazil.

ABSTRACT

Objective: To evaluate the influence of intersomatic spacers used in ALIF on segmental lordosis and height of the intervertebral foramen. Methods: Intersomatic spacers with different heights (17, 18, 20 and 24 mm), length (20, 25 and 30 mm), and angulation (30 and 40 degrees) were introduced in segments L4-L5 and L5-S1 of two adult cadavers according to the ALIF technique. The lordosis of the vertebral segment and the height of the intervertebral foramina were evaluated before and after placement of the different intersomatic spacers. Results: An increase in segmental lordosis was observed with the placement of spacers in relation to the initial values. No statistical difference was observed between the different intersomatic spacers. The height of the intervertebral foramen increased with the placement of spacers and a statistical difference was observed between the different intersomatic spacers. Conclusion: Segmental lordosis increased with the placement of spacers compared to the control group. There was no statistical difference between the different heights and angles of the spacers. The height of the intervertebral foramen increased with the introduction of spacers. A statistically significant difference was observed with the increase in height and angle of the spacers. ***Level of Evidence III; Experimental study.***

Keywords: Spinal Fusion, Lordosis, Vertebral foramen.

RESUMO

Objetivo: Avaliar a influência dos espaçadores intersomáticos utilizados no ALIF sobre a lordose segmentar e altura do forame intervertebral. Métodos: Espaçadores intersomáticos com diferentes alturas (17, 18, 20 e 24 mm), comprimento (20, 25 e 30mm), e angulação (30 e 40 graus) foram introduzidos nos segmentos L4-L5 e L5-S1 de dois cadáveres adultos de acordo com a técnica do ALIF. A lordose do segmento vertebral e a altura dos forames intervertebrais foram avaliados antes e após a colocação dos diferentes espaçadores intersomáticos. Resultados: Foi observado aumento da lordose segmentar com a colocação dos espaçadores em relação aos valores iniciais. Não foi observado diferença estatística entre os diferentes espaçadores intersomáticos. A altura do forame intervertebral aumentou com a colocação dos espaçadores e foi observado diferença estatística entre os diferentes espaçadores intersomáticos. Conclusão: A lordose segmentar apresentou aumento com a colocação dos espaçadores em relação ao grupo controle. Não se observou diferença estatística entre as diferentes alturas e angulações dos espaçadores. A altura do forame intervertebral aumentou com a introdução dos espaçadores. Observou-se diferença estatística significativa com o aumento da altura e angulação dos espaçadores. ***Nível de evidência III; Estudo experimental.***

Descritores: *Fusão Vertebral, Lordose, Forame Vertebral.*

RESUMEN

Objetivo: Evaluar la influencia de los espaciadores intersomáticos utilizados en ALIF sobre la lordosis segmentaria y la altura del agujero intervertebral. Métodos: Se introdujeron espaciadores intersomáticos con diferentes alturas (17, 18, 20 y 24 mm), ancho (20, 25 y 30 mm) y ángulo (30 y 40 grados) en los segmentos L4-L5 y L5-S1 de dos cadáveres adultos. de acuerdo con la técnica del ALIF. Se evaluó la lordosis del segmento vertebral y la altura del agujero intervertebral antes y después de la colocación de los diferentes espaciadores intersomáticos. Resultados: Foi observado aumento da lordose segmentar com colocação dos espaçadores em relación aos valores iniciados. Não foi observado diferença estatística entre os diferentes espaciadores intersomáticos. A altura do forame intervertebral aumengou com colocação dos espaciadores e foi observado diferença estatística entre os diferentes espaciadores intersomáticos. Conclusión: La lordosis segmentaria presentó un aumento con la colocación de espaciadores en relación al grupo control. Não se observou diferença estatística entre as diferentes alturas y angulações dos espaçadores. La altura del agujero intervertebral aumentó con la introducción de espaciadores. Observe las diferencias estadísticas significativas con el aumento de altura y el ángulo de los espaciadores. ***Nivel de Evidencia III; Estudio experimental.***

Descriptores**:** *Fusión Vertebral, Lordosis, Foramen Vertebral.*

Study conducted by the Universidade de São Paulo, Ribeirão Preto Medical School, Department of Orthopedics and Anesthesiology, USP Campus, University City, Ribeirão Preto, SP, Brazil. 14040-900.
Correspondence: Helton Luiz Aparecido Defino, 3900, Bandeirantes Ave, Monte Alegre, Ribeirão Preto, SP, Brazil. 14040-900. hladefin@fmrp.usp.br

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

INTRODUCTION

Anterior lumbar interbody fusion (ALIF) has been performed as an alternative for the treatment of a wide range of lumbar spine diseases (trauma, degenerative, infection, tumor, deformity, iatrogenic). The indication for ALIF has as its main objectives the stabilization of the vertebral segment, restoration of segmental lordosis (SL), and indirect decompression of the nervous structures by increasing the height of the vertebral foramen.[1-3]

Initially, ALIF was performed only with bone grafts, and during the evolution of the technique, interbody spacers were introduced.[4] The insufficient reconstruction of the SL with non-angled spacers motivated the development of lordotic interbody spacers, which theoretically would offer advantages for the restoration of the vertebral segment lordosis.[3,5,6] However, this theoretical advantage remains not well defined.[2,3]

Indirect decompression of neural structures by increasing the height of the vertebral foramen is another feature of ALIF and has been reported in clinical and experimental studies. The increase in the height of the vertebral foramen has been observed with the use of cylindrical and conical spacers.[7,8]

At the moment, the interbody spacers used in ALIF have a lordotic angle, which was introduced to enhance the restoration of the segment's lordosis. There is a wide variety of this type of interbody spacer available for performing ALIF.[9]

The study's development considered the changes in the lordosis of the vertebral segment, which is directly related to the maintenance or restoration of the sagittal balance of the spine, functional outcomes, and the height of the intervertebral foramen induced by the introduction of the interbody spacer into the disc space, which leads to the indirect decompression of the neural structures.[7,9]

The objective of the study was to evaluate and compare the changes in the SL of the L4-L5 and L5-S1 segments, and the height of the respective intervertebral foramina after the introduction of anterior interbody spacers with different heights, lengths, and angles.

MATERIAL AND METHODS

The study was approved by the Local Research Ethics Committee (CAAE: 78956323.7.0000.5440), and carried out at the Anatomy Laboratory of the Ribeirão Preto Medical School - USP. Segments of the lumbar spine (L4-L5-S1) from two adult cadavers were used. The selected vertebral segments for the study did not show macroscopic and radiographic changes related to disease or surgical procedure.

Spacers developed for anterior interbody fusion of the lumbar spine were used. The spacers were of the SAGA model (Vincula®) with different heights (17, 18, 20, and 24 mm), lengths (20, 25, and 30mm), and angles (30 and 40 degrees). The spacers were identified by three numbers (for example: 17x20x30). The first number indicates the height in millimeters, the second the length in millimeters, and the third the angle in degrees. (Figure 1)

The experimental model simulated the performance of ALIF in the L4-L5 and L5-S1 disc spaces with the placement of spacers of different dimensions and the measurement of the lumbar segment angulation and the height of the intervertebral foramen. (Figure 2)

The measurement of the parameters selected for the study (segmental lordosis and intervertebral foramen height) was performed before the removal of the intervertebral disc and preparation of the disc space for the placement of the spacers, and after the placement of spacers of different dimensions inside the disc space. The values of the vertebral segment angulation and the height of the intervertebral foramen before the placement of the spacers were considered as the control group.

The spacers were introduced in an increasing manner considering their height (17,18,20, and 24mm), length (20, 25, and 30 mm), and angulation (30 and 40 degrees). The spacers were introduced in a standardized manner and their anterior surface was aligned with the anterior face of the vertebral bodies of the studied segment.

The height of the intervertebral foramen was determined by its direct measurement in the craniocaudal direction. The vertebral notch of the pedicle of the superior vertebra and the vertebral notch of the pedicle of the inferior vertebra were the anatomical references used for measurement. The measurement was carried out with a universal caliper from the HTOM brand, model in stainless steel 6 inches - 150mm, with a graduation of 0.05mm and certified precision.

The angulation of the vertebral segment was measured on lateral radiographs of the lumbar spine. The angulation of the vertebral plates of the L4-L5 and L5-S1 segments were the anatomical references for measuring the angulation of the vertebral segment. (Figure 3)

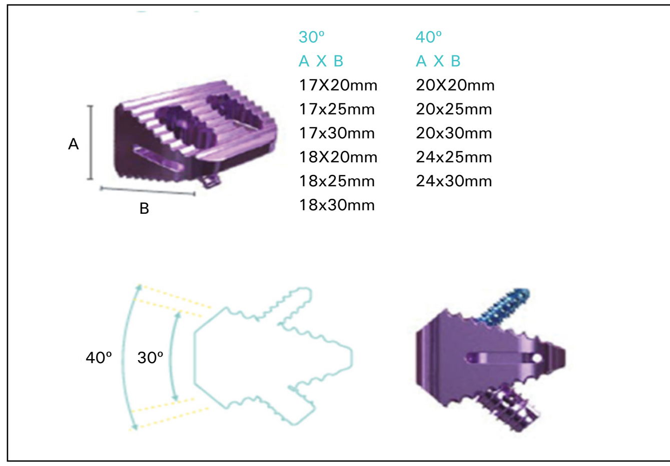

Figure 1. Interbody spacers used and characteristics of their dimensions.

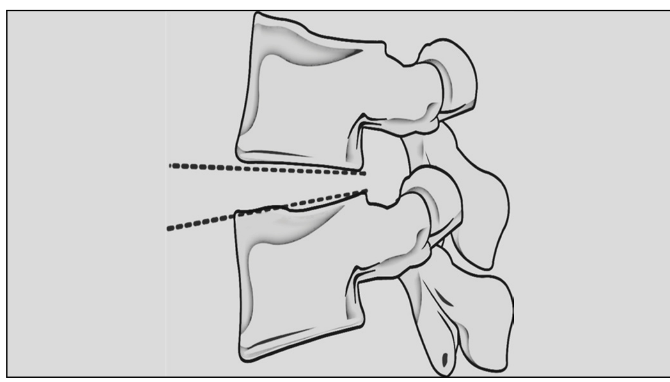

Figure 2. Drawing illustrating the angulation of the vertebral segment and the height of the intervertebral foramen.

Figure 3. Lateral radiograph of the vertebral segment with the spacer positioned and the anatomical references for measuring the angulation of the vertebral segment.

The statistical study was conducted using descriptive statistics (minimum value, maximum value, mean, and standard deviation of the studied groups). The Shapiro-Wilk test was used to assess the normality of the samples. The ANOVA, Tukey, and t-Student tests were used to compare the results of the vertebral segment angulation and intervertebral foramen height. The correlation between the dimensions of the intersomatic spacer with the segmental lordosis and height of the intervertebral foramen was performed using the Spearman test. The study established a significance level of 5% ($p<0.05$) for the statistical difference.

It was observed the trend of increased segmental lordosis with the increase in height and angulation of the interbody spacers in the segments considering all intervertebral spaces (L4-L5 and L5-S1). A statistical difference (ANOVA-Tukey -$p<0.05$) was observed between all spacer modalities with heights of 18, 20, and 24mm in relation to the segmental lordosis of the control group. Although a trend of increased segmental lordosis with increased height and angulation of the spacers was observed, no statistical difference was found. However, the small sample size of the study may interfere with this result (Table 1 and Figure 4).

The angulation of the vertebral segment did not show a statistical difference with the variation in the length of the intersomatic spacers (ANOVA-Tukey test and Student's t-test- $p<0.05$) in the different subgroups with similar height and angulation. (Figure 5)

The analysis of the individualized segmental angulation for each vertebral segment (L4-L5 and L5-S1) with the placement of the interbody spacer is represented in figures 5 and 6. It was observed the trend of increasing segmental angulation with the use of spacers with greater height and angulation. The increase in segmental lordosis did not occur similarly in the disc spaces and a trend of greater angular increase was observed in the L5-S1 disc space. (Figure 6 and 7)

A correlation was observed between the height (17,18,20 or 24 mm) and the angulation (30 and 40 degrees) of the spacer with the segmental lordosis. (Spearman – $r = 0.9506$ and 0.8157 – $p< 0.05$). No correlation was observed between the depth of the spacer used in the study and the segmental lordosis.

The height of the intervertebral foramen on both sides of the L4-L5 and L5-S1 segments are illustrated in Table 2. The values showed symmetry in the specific vertebral segment, and a tendency to increase with the increase in height and angulation of the spacer. A correlation was observed between the height of the intersomatic spacer (17, 18, 20, and 24 mm) and angulation (30 or 40 degrees) with the height of the intervertebral foramen (Spearman – $r=0.9722/0.8680$- $p<0.05$). No correlation was observed between the length of the intersomatic spacer and the height of the intervertebral foramen.

The height of the intervertebral foramen showed variation from normal values (control without intersomatic spacer) in the L4-L5 and L5-S1 segments, and the height at the L5-S1 level was lower. Symmetry of the values (right and left side) of the height of the intervertebral foramen was observed in the control group and after the placement of the intersomatic spacers. The placement of intersomatic spacers increased the height of the intervertebral foramen compared to the control group (Figure 8 and 9), with a statistical difference observed between the different dimensions of the spacers. (Table 2)

The height of the vertebral foramina (L4-L5-S1) increased with the placement of the spacers and a statistical difference was observed with all spacer dimensions compared to the control group. (ANOVA-Tukey-$p<0.05$). (Figure 7 and 8). The statistical differences between the different types of intersomatic spacers in relation to the height of the intervertebral foramen are illustrated in table 3, showing the greatest increase in the height of the intervertebral foramen with the increase in height and angulation of the intersomatic spacer. The length of the spacer influenced the height of the vertebral foramen in some subgroups. (Figure 10)

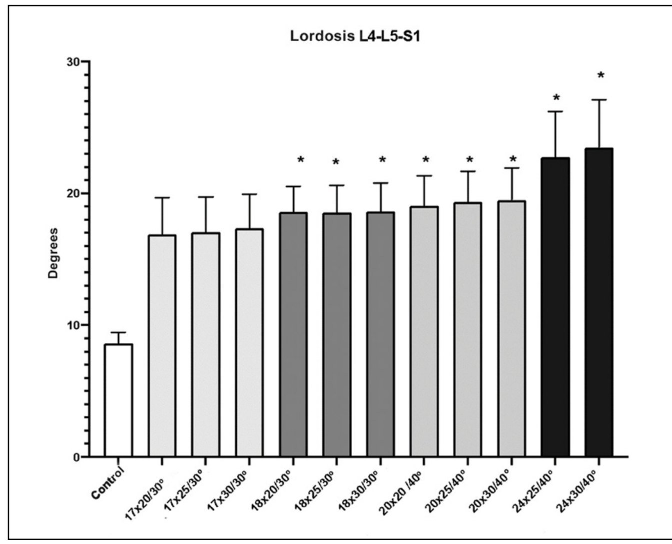

Figure 4. Graph illustrating the angulation of the vertebral segment with the placement of interbody spacers of different dimensions. The asterisk (*) indicates a statistical difference compared to the control. (ANOVA-Tukey test-$p<0.05$).

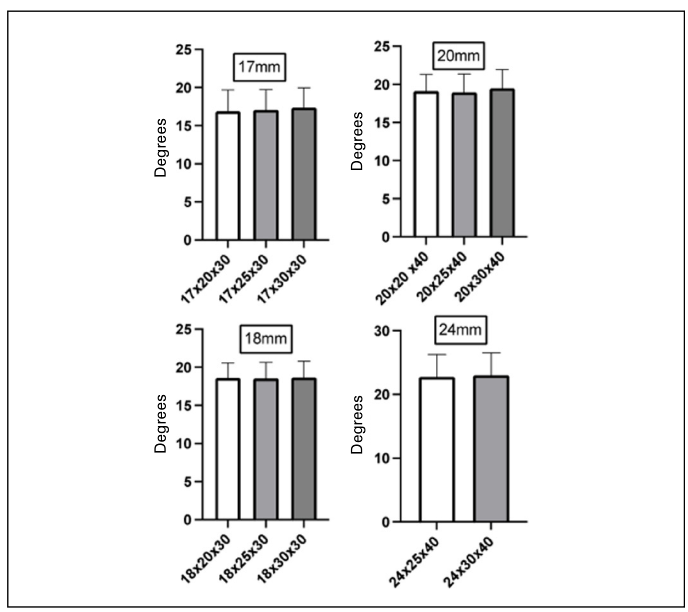

Figure 6. Graph illustrating segmental lordosis in subgroups with similar height and angulation and different lengths.

Table 1. Segmental lordosis in the L4-L5_S1 segments in the control group and all spacer modalities.

	Control	17x20x30	17x25x30	17x30x30	18x20x30	18x25x30	18x30x30	20x20 x40	20x25x40	20x30x40	24x25x40	24x30x40
Column 1-L4-L5	7.4	16.4	16.8	16.8	17.3	17.2	17.3	17.8	17.8	17.9	18.8	19
Column 1- L5-S1	8.9	21	20.9	21.1	21.2	21.3	21.5	22	22.3	22.6	23.2	24.1
Column 2 L4-L5	9	14.9	15	15.2	16.9	16.7	16.7	19.6	16.7	17.2	21.8	21.8
Column 2- L5-S1	9.2	15.3	15.6	16.4	18.9	19	19.1	17.2	19	20.3	27.2	27.2
Average	8.625	16.9	17.08	17.38	18.58	18.55	18.65	19.15	18.95	19.5	22.75	23.03
DP	0.8261	2.806	2.658	2.575	1.952	2.082	2.156	2.156	2.423	2.456	3.489	3.478

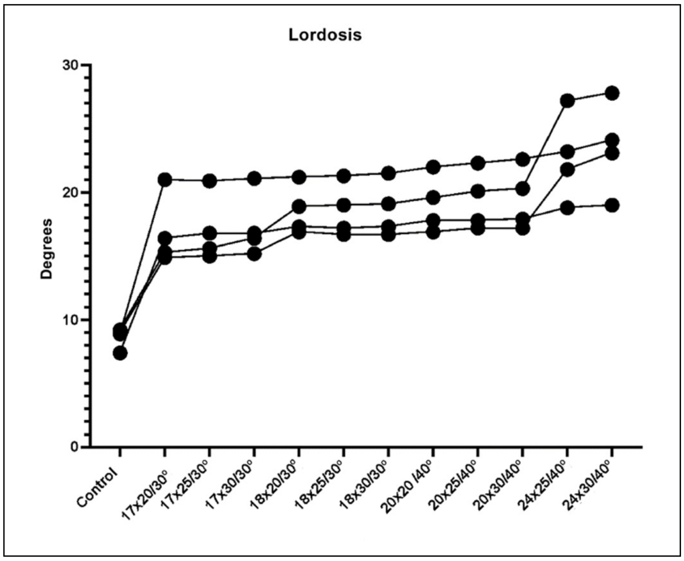

Figure 6. Graph illustrating the angulation of the L4-L5 and L5-S1 vertebral segments in the control group and after the placement of the intersomatic spacer. The spacers of different dimensions (height x width x angulation) are represented on the abscissa.

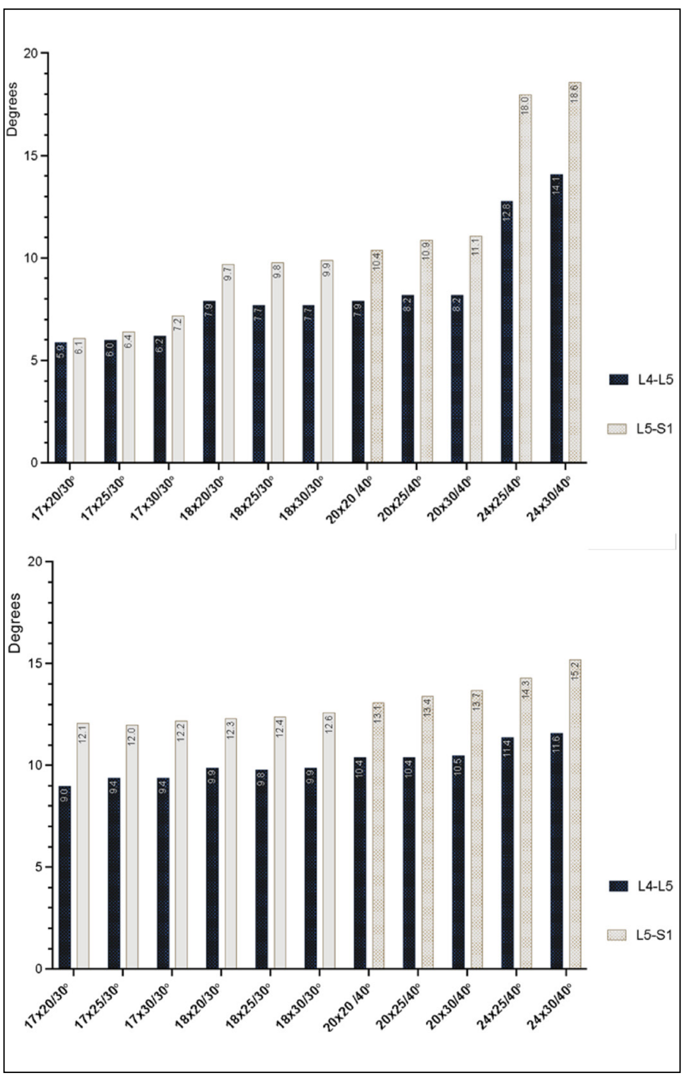

Figure 7. Graphs illustrating in each specimen the increase in segmental lordosis in the L4-L5 and L5-S1 disc spaces after the placement of the interbody spacer.

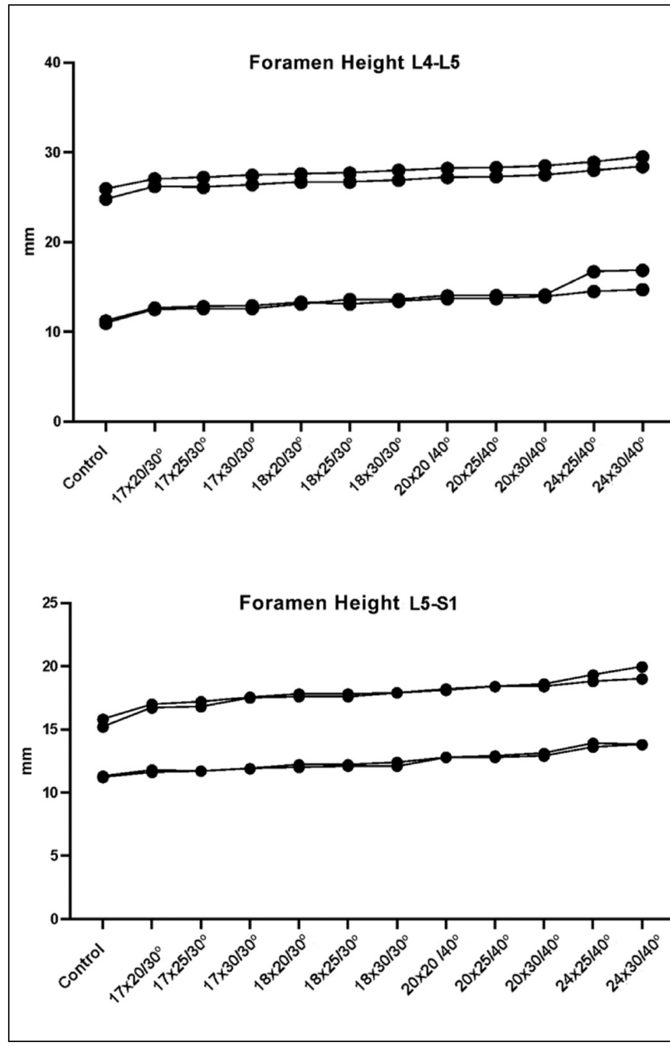

Figure 8. Individual behavior of the height of the intervertebral foramen of the L4-L5 and L5-S1 segment in the control group and after the placement of the spacers. The pair of curves (upper and lower) indicate the values of the height of the intervertebral foramen on the right and left sides of the L4-L5 and L5-S1 segments of each lumbar spine studied.

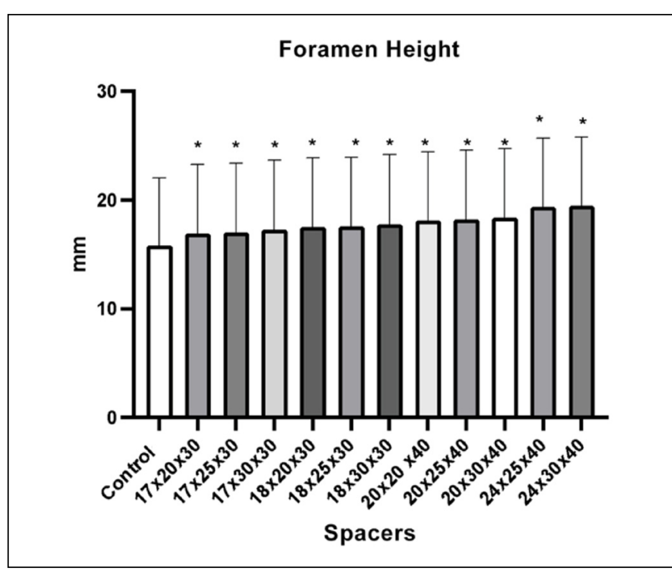

Figure 9. Graph illustrating the height of the intervertebral foramen with the different dimensions of the intervertebral spacer. The asterisk (*) indicates the statistical difference in relation to the control group. (ANOVA-Tukey- $p<0.05$)

Table 2. Values of the vertebral foramina (right and left) and segmental lumbar lordosis (L4-L5 and L5-S1) of the control group and after the placement of the vertebral spacers. The numbers referring to the spacers indicate from left to right: the height, the length, and the angulation.

Column	Spacer	Level	Foramen L	Foramen R	Lordosis segment
1	Control	L4-L5	11.2	10.95	7.4
1	Control	L5-S1	11.2	11.3	8.9
1	17x20x30	L4-L5	12.65	12.5	16.4
1	17x20x30	L5-S1	11.6	11.8	21
1	17x25x30	L4-L5	12.8	12.6	16.8
1	17x25x30	L5-S1	11.7	11.7	20.9
1	17x30x30	L4-L5	12.9	12.6	16.8
1	17x30x30	L5-S1	11.9	11.9	21.1
1	18x20x30	L4-L5	13.3	13.1	17.3
1	18x20x30	L5-S1	12.2	12	21.2
1	18x25x30	L4-L5	13.1	13.6	17.2
1	18x25x30	L5-S1	12.2	12.1	21.3
1	18x30x30	L4-L5	13.4	13.6	17.3
1	18x30x30	L5-S1	12.4	12.1	21.5
1	20x20 x40	L4-L5	13.7	14	17.8
1	20x20 x40	L5-S1	12.8	12.8	22
1	20x25x40	L4-L5	13.7	14.05	17.8
1	20x25x40	L5-S1	12.9	12.8	22.3
1	20x30x40	L4-L5	13.9	14.1	17.9
1	20x30x40	L5-S1	13.1	12.9	22.6
1	24x25x40	L4-L5	14.5	16.7	18.8
1	24x25x40	L5-S1	13.9	13.6	23.2
1	24x30x40	L4-L5	14.7	16.85	19
1	24x30x40	L5-S1	13.8	13.8	24.1
2	Control	L4-L5	24.8	25.95	9
2	Control	L5-S1	15.2	15.8	9.2
2	17x20x30	L4-L5	26.2	27.05	14.9
2	17x20x30	L5-S1	16.7	17	15.3
2	17x25x30	L4-L5	26.1	27.2	15
2	17x25x30	L5-S1	16.8	17.2	15.6
2	17x30x30	L4-L5	26.4	27.45	15.2
2	17x30x30	L5-S1	17.5	17.55	16.4
2	18x20x30	L4-L5	26.7	27.6	16.9
2	18x20x30	L5-S1	17.6	17.8	18.9
2	18x25x30	L4-L5	26.7	27.7	16.7
2	18x25x30	L5-S1	17.6	17.8	19
2	18x30x30	L4-L5	26.9	28	16.7
2	18x30x30	L5-S1	17.9	17.9	19.1
2	20x20x40	L4-L5	27.2	28.2	16.9
2	20x20x40	L5-S1	18.1	18.2	19.6
2	20x25x40	L4-L5	27.3	28.3	17.2
2	20x25x40	L5-S1	18.4	18.4	20.1
2	20x30x40	L4-L5	27.5	28.5	17.2
2	20x30x40	L5-S1	18.4	18.6	20.3
2	24x25x40	L4-L5	28	28.9	21.8
2	24x25x40	L5-S1	18.8	19.3	27.2
2	24x30x40	L4-L5	28.4	29.5	23.1
2	24x30x40	L5-S1	19	19.95	27.8
		Average	17.58	17.99	18.33
		DP	5.78	6.16	4.14

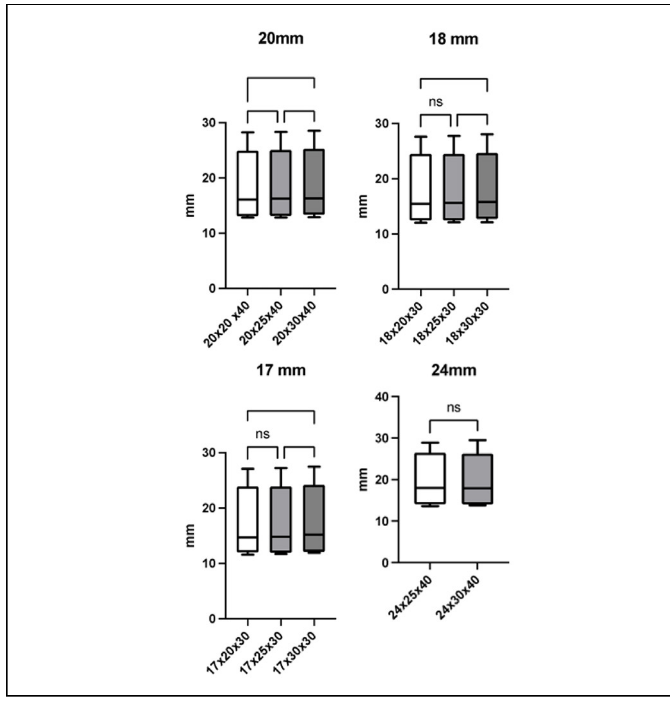

Figure 10. Graph illustrating the influence of spacer length on the height of the vertebral foramen. The asterisk indicates statistical difference (ANOVA-Tukey test and t-Student-p<0.05.

DISCUSSION

The lordosis of the vertebral segment and the height of the intervertebral foramen showed changes induced by the dimensions of the intervertebral spacer used for ALIF.

The lordotic spacers used in ALIF were developed to enhance the restoration of vertebral segmental lordosis. The theoretical advantage of using lordotic spacers for this purpose has been questioned in clinical reports (3, 10). Lordotic spacers have not shown a significant statistical role in the correction of segmental lordosis.[3,10] Although there are reports of their impact on lumbar and segmental lordosis.[2,11-13]

The influence of the height and angulation of the spacers on the segmental lordosis has been controversial.[2,11,13] There are reports showing that increasing the angulation of the spacers with the same height would not increase the segmental lordosis.[2,3] Spacers without intrinsic lordosis would present greater correction of segmental lordosis compared to spacers with intrinsic lordosis due to the fulcrum effect of rotation. In spacers without intrinsic angulation, the fulcrum of rotation would be located more posteriorly and would exert a greater effect on segmental lordosis.[7,14]

The results of our study showed a trend of increased segmental lordosis with the increase in height and angulation of the spacers

Table 3. Representation of the comparison of the height of the intervertebral foramina (L4-L5-S1) between the control group and the different dimensions of the spacers. The ANOVA statistical method followed by the Tukey method was used and established p<0.05. NS represents values of p > or = 0.05. Asterisks indicate: (*) indicates p-value from 0.01 to 0.05; (**) from 0.001 to 0.01; (***) from 0.0001 to 0.001 <0.0010; and (****) <0.0001.

	17x20/30	17x25/30	17x30/30	18x20/30	18x25/30	18x30/30	20x20 /40	20x25/40	20x30/40	24x25/40	24x30/40
Control	**	**	**	**	**	**	***	***	****	***	***
17x20/30	NS	NS	NS	**	**	**	****	****	****	**	***
17x25/30	NS	NS	NS	***	**	***	****	****	****	**	***
17x30/30	NS	NS	NS	*	NS	NS	***	****	****	*	**
18x20/30	NS	NS	NS	NS	NS	NS	***	***	***	*	**
18x25/30	NS	NS	NS	NS	NS	NS	****	****	****	**	***
18x30/30	NS	NS	NS	NS	NS	NS	**	***	****	*	**
20x20 /40	NS	NS	NS	NS	NS	NS	NS	NS	**	*	*
20x25/40	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	*
20x30/40	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
24x25/40	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

compared to the control. The statistical difference between the groups in which the spacer was used was not observed, but the small sample size available for the study should be considered in the interpretation of the results. The greatest correction of segmental lordosis was observed in the spacers with greater height and greater angulation. However, the study design does not allow the isolated influence of the height and angulation of the intervertebral spacer on segmental lordosis to be identified. These parameters showed correlation with segmental lordosis, and this correlation was not observed with the width of the spacer.

ALIF has shown superior correction of segmental lordosis compared to other techniques, and the resection of the anterior longitudinal ligament, which must be performed to access the disc, has been pointed out as more responsible than the spacer's own angulation.[3,9] Additionally, the anterior positioning of the spacer, always present in ALIF, and the reason why we kept the spacers at the anterior edge of the vertebral body during the experiments, also contributes to segmental lordosis.[3,7]

The definition and limits of the intervertebral foramen present controversies despite numerous clinical and experimental reports.[9,15] The stenosis of the vertebral canal and intervertebral foramen that occurs in degenerative diseases of the spine is the result of the reduction in the height of the intervertebral disc associated with changes in the articular facets, bulging of the yellow ligament, articular capsule, and protrusion of the intervertebral disc.[9,15] These changes alter the shape and dimensions of the intervertebral foramen with consequent compression of the nerve roots contained within it.[15-17]

The ALIF, in addition to stabilizing the vertebral segment, allows for indirect decompression of neural structures by restoring disc space height.[7,9] Reports indicate that ALIF is superior to TLIF in restoring intervertebral space height and indirect decompression of the intervertebral foramen.[9] Indirect decompression of neural structures has been evidenced in clinical and experimental studies.[17-21]

With the exception of elderly patients with a high degree of bone compression or loss of disc space height due to subsidence, indirect decompression has allowed decompression of the nerve structures within the intervertebral foramen.[7,8] Vertebral segments with greater intrinsic flexibility have shown greater correction of the dimensions of the intervertebral foramen through indirect decompression.[17] In a study using cadavers, it was observed that the restoration of disc space height would only be able to increase the height of the intervertebral foramen. The width of the intervertebral foramen would be related to the diameter of the vertebral canal and the length of the pedicles. Restoring only the height of the intervertebral foramen would not be sufficient to decompress the neural structures.[15]

The results of our study showed the influence of the height and angulation of the spacer on the increase in the height of the intervertebral foramen, indicating the potential of indirect decompression with the increase in the height and angulation of the spacer. The study evidenced the trend of increasing the height of the intervertebral foramen with the increase in height and angulation of the intersomatic spacer.

The study presents deficiencies related to the sample size, reflecting the difficulty of obtaining cadaver spine segments in our environment. The small sample hinders the statistical study and the evaluated parameters cannot be analyzed in isolated levels of the lumbar spine. The analysis carried out on the difference in correction between the L4-L5 and L5-S1 levels highlights this difficulty. Despite the small sample, the experiment was conducted in a way to eliminate the variables involved in performing the ALIF with spacers, making its execution homogeneous.

The width and length of the intersomatic spacers are important to increase the contact surface and stability of the ALIF.[9] In our study, the length of the spacer did not influence the angulation of the vertebral segment, and differences were observed regarding the height of the vertebral foramen.

The restoration of the angulation of the vertebral segment and the indirect decompression of the intervertebral foramen is multifactorial, and the dimensions and designs of the spacers belong to the constellation of factors involved in the performance of ALIF.[22,23] The presented results, although derived from an experimental study, provide support for the clinical application of ALIF for the restoration of the angulation of the vertebral segment and the height of the vertebral foramen.

CONCLUSION

The use of angled intervertebral spacers in the ALIF technique allowed for an increase in the angulation of the vertebral segment compared to the control group, and a trend towards increased correction with greater height and angulation of the spacer. However, no statistical difference was observed between spacers with different dimensions.

The height of the intervertebral foramen showed a statistical difference compared to the control, highlighting the influence of the increased height and angulation of the interbody spacer on the indirect decompression of the vertebral foramen. A statistical difference was observed with the increase in height and angulation of the spacer on the increase in height of the intervertebral foramen. The length of the spacer showed a statistical difference in some subgroups.

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, and MPD: support in scientific writing for the study and review; HLAD: substantial contributions to the study's conception; acquisition and interpretation of data for the study. Guidance and final approval of the version of the manuscript to be published.

REFERENCES

1. Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg. 2015;1(1):2-18.
2. Uribe JS, Myhre SL, Youssef JA. Preservation or Restoration of Segmental and Regional Spinal Lordosis Using Minimally Invasive Interbody Fusion Techniques in Degenerative Lumbar Conditions: A Literature Review. Spine (Phila Pa 1976). 2016;41 Suppl 8:S50-8.
3. 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.
4. Phan K, Mobbs RJ. Evolution of Design of Interbody Cages for Anterior Lumbar Interbody Fusion. Orthop Surg. 2016;8(3):270-7.
5. Than KD, Park P, Fu KM, Nguyen S, Wang MY, Chou D, Nunley PD, et al. Clinical and radiographic parameters associated with best versus worst clinical outcomes in minimally invasive spinal deformity surgery. J Neurosurg Spine. 2016;25(1):21-5.
6. Haque RM, Mundis GM Jr, Ahmed Y, El Ahmadieh TY, Wang MY, Mummaneni PV, et al. Comparison of radiographic results after minimally invasive, hybrid, and open surgery for adult spinal deformity: a multicenter study of 184 patients. Neurosurg Focus. 2014;36(5):E13.
7. Wang M, Dalal S, Bagaria VB, McGrady LM, Rao RD. Changes in the lumbar foramen following anterior interbody fusion with tapered or cylindrical cages. Spine J. 2007;7(5):563-9.
8. Derman PB, Ohnmeiss DD, Lauderback A, Guyer RD. Indirect Decompression for the Treatment of Degenerative Lumbar Stenosis. Int J Spine Surg. 2021;15(6):1066-1071.
9. Phan K, Thayaparan GK, Mobbs RJ. Anterior lumbar interbody fusion versus transforaminal lumbar interbody fusion--systematic review and meta-analysis. Br J Neurosurg. 2015;29(5):705-11.
10. Kadam A, Wigner N, Saville P, Arlet V. Overpowering posterior lumbar instrumentation and fusion with hyperlordotic anterior lumbar interbody cages followed by posterior revision: a preliminary feasibility study. J Neurosurg Spine. 2017;27(6):650-660.
11. Lee CH, Chung CK, Jang JS, Kim SM, Chin DK, Lee JK, et al. Effectiveness of deformity-correction surgery for primary degenerative sagittal imbalance: a meta-analysis. J Neurosurg Spine. 2017;27(5):540-551.
12. Saville PA, Kadam AB, Smith HE, Arlet V. Anterior hyperlordotic cages: early experience and radiographic results. J Neurosurg Spine. 2016;25(6):713-719.

13. Melikian R, Yoon ST, Kim JY, Park KY, Yoon C, Hutton W. Sagittal Plane Correction Using the Lateral Transpsoas Approach: A Biomechanical Study on the Effect of Cage Angle and Surgical Technique on Segmental Lordosis. Spine (Phila Pa 1976). 2016;41(17):E1016-E1021.
14. Hueng DY, Chung TT, Chuang WH, Hsu CP, Chou KN, Lin SC. Biomechanical effects of cage positions and facet fixation on initial stability of the anterior lumbar interbody fusion motion segment. Spine (Phila Pa 1976). 2014;39(13):E770-6.
15. Cinotti G, De Santis P, Nofroni I, Postacchini F. Stenosis of lumbar intervertebral foramen: anatomic study on predisposing factors. Spine (Phila Pa 1976). 2002;27(3):223-9.
16. Mayoux-Benhamou MA, Revel M, Aaron C, Chomette G, Amor B. A morphometric study of the lumbar foramen. Influence of flexion-extension movements and of isolated disc collapse. Surg Radiol Anat. 1989;11(2):97-102.
17. Hasegawa T, An HS, Haughton VM, Nowicki BH. Lumbar foraminal stenosis: critical heights of the intervertebral discs and foramina. A cryomicrotome study in cadavera. J Bone Joint Surg Am. 1995;77(1):32-8..
18. Kapustka B, Kiwic G, Chodakowski P, Miodoński JP, Wysokiński T, Łączyński M, et al. Anterior lumbar interbody fusion (ALIF): biometrical results and own experiences. Neurosurg Rev. 2020;43(2):687-693.
19. Rao PJ, Maharaj MM, Phan K, Lakshan Abeygunasekara M, Mobbs RJ. Indirect foraminal decompression after anterior lumbar interbody fusion: a prospective radiographic study using a new pedicle-to-pedicle technique. Spine J. 2015;15(5):817-24.
20. Schlegel JD, Champine J, Taylor MS, Watson JT, Champine M, Schleusener RL, Savory KM. The role of distraction in improving the space available in the lumbar stenotic canal and foramen. Spine (Phila Pa 1976). 1994;19(18):2041-7.
21. Chen D, Fay LA, Lok J, Yuan P, Edwards WT, Yuan HA. Increasing neuroforaminal volume by anterior interbody distraction in degenerative lumbar spine. Spine (Phila Pa 1976). 1995;20(1):74-9.
22. Kepler CK, Huang RC, Sharma AK, Meredith DS, Metitiri O, Sama AA, Girardi FP, Cammisa FP. Factors influencing segmental lumbar lordosis after lateral transpsoas interbody fusion. Orthop Surg. 2012;4(2):71-5.
23. Barrey C, Darnis A. Current strategies for the restoration of adequate lordosis during lumbar fusion. World J Orthop. 2015;6(1):117-26.