ORIGINAL ARTICLE

# EXPERIMENTAL STUDY OF LIGAMENTOTAXIS MANEUVERS SEQUENCING IN VERTEBRAL CANAL DECOMPRESSION

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## SUMMARY

Vertebral canal decompression, intended to provide relief to nervous structures, may be performed by means of ligamentotaxis. The objective of this study was to assess the influence of the ligamentotaxis sequence on vertebral canal decompression. Vertebral segments of Landrace swine specimens were used. A device especially developed for producing a burst-type fracture was employed. Subsequently to the computerized tomography scan, 10 specimens that best showed a burst-type fracture were fixated with internal fixator (Synthes). Two groups were formed. On the first group (n=5), lordosis followed by distraction were performed. Then, they were submitted to distraction and lordosis. On the second group (n=5), distraction was provided first, and then lordosis was performed. After each maneuver, vertebral canal was measured by tomography scan. Fractured vertebral body fragments were measured and compared using the Student's t test ($p \leq 0.05$). By comparing dislocations between groups, no statistical differences were found ($p \leq 0.06$). This result is close to the significance level adopted, suggesting a strong trend towards a better effectiveness of the maneuver started with lordosis.

***Keywords:*** *Vertebral spine fractures; Lumbar vertebrae; Fractures, internal fixation; Follow-up.*

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## INTRODUCTION

Thoracolumbar spine fractures may be associated with nervous structures injuries comprised within vertebral canal, caused by the impact produced by the displacement of a fractured vertebral body's posterior wall fragments[1-3].

Vertebral canal decompression may be performed by a direct method (anterior or posterolateral decompression) or indirect method (ligamentotaxis)[1,3,4] (Figure 1). The indirect decompression of vertebral canal, the so-called ligamentotaxis, is closely related to posterior longitudinal ligament (PLL). PLL stress acts as an arc rope, displacing fragments of vertebral body's posterior wall, thus allowing its reduction and vertebral canal decompression. Ligamentotaxis is influenced by PLL anatomical integrity, by fracture morphology and by the surgical technique employed, with injured vertebral segment distraction by means of implants applied on the posterior surface of the vertebral spine the most effective way to provide tension to posterior longitudinal ligament[5-7]. Even though lordosis restoring is not the main correction mechanism, it also helps on ligamentotaxis and has been described as a step of the technique when employed with internal fixator[8].

The objective of this study was to experimentally assess the effects of correction maneuvers sequencing with the use of internal fixator (lordosis and distraction) for repositioning fractured vertebral body's posterior wall fragments and, as a result, for decompressing vertebral canal. The question asked in the experiment was the following: What is the optimal maneuver to achieve maximum vertebral body's posterior wall fragment repositioning during ligamentotaxis: lordosis followed by distraction, or distraction followed by lordosis?

## MATERIALS AND METHODS

Thirty vertebral spine segments removed from 6 month-old hybrid swine weighting 102 Kg in average were used in the study. The T12-T13-L1 segment (swine have 13 thoracic vertebrae) was selected for the study and fracture was produced on T13 vertebra by axial compression with the aid of a device specially built for this end. (Figure 2)

The basic principle of the device operation was the transfer of axial impact by means of a cylinder on vertebral segment T12-T13-L1. The 34-kg lead cylinder slid down from a distance of 100 cm, guided by a metal bar, hitting the T12-T13-L1 segment.

Axial compression fractures were produced on the 30 spine segments, and 10 segments were selected based on data provided by imaging tests (X-ray and computed tomography scan). The 10 selected segments showed homogenous morphological characteristics of burst-like fracture.

The 10 spine segments selected for the study were fixated by means of an internal fixator (Synthes) using Schanz's pins on T12 and L1 vertebral pedicles. After the internal fixator was inserted, ligamentotaxis maneuvers were performed, and the specimens were divided into two groups of five vertebral segments. Each group was identified and characterized according to the sequence of distraction and lordosis steps. Group I was named as (lor+dis), where lordosis was performed first, followed by distraction during

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ligamentotaxis maneuvers. Group II was named as (dis+lor), on which distraction was made first, and then followed by lordosis. After ligamentotaxis maneuvers, lordosis + distraction or distraction + lordosis), the specimens were submitted to tomography scan with 3-mm takes for assessing vertebral canal width. The distance between the posterior edge of the fractured vertebral body's fragment and the anterior edge of the mean point of the vertebral arc was standardized in order to measure vertebral canal width. (Figures 3 and 4)

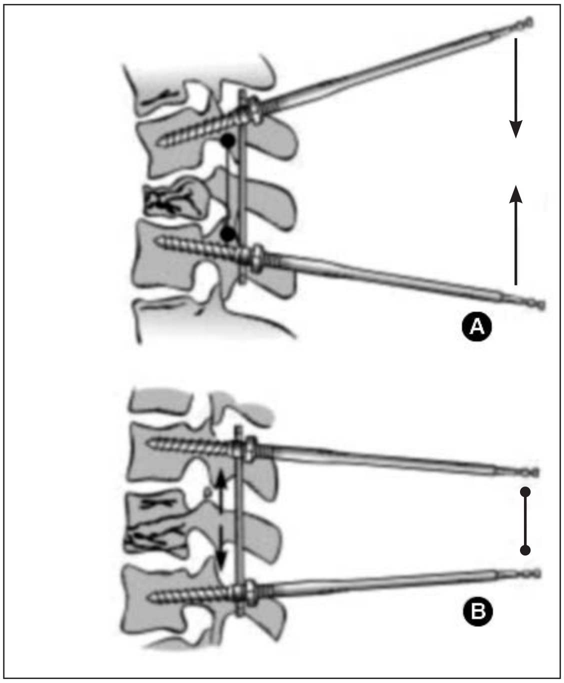


Figure 1 - *Ligamentotaxis maneuvers: lordosis (a) and distraction (b).*

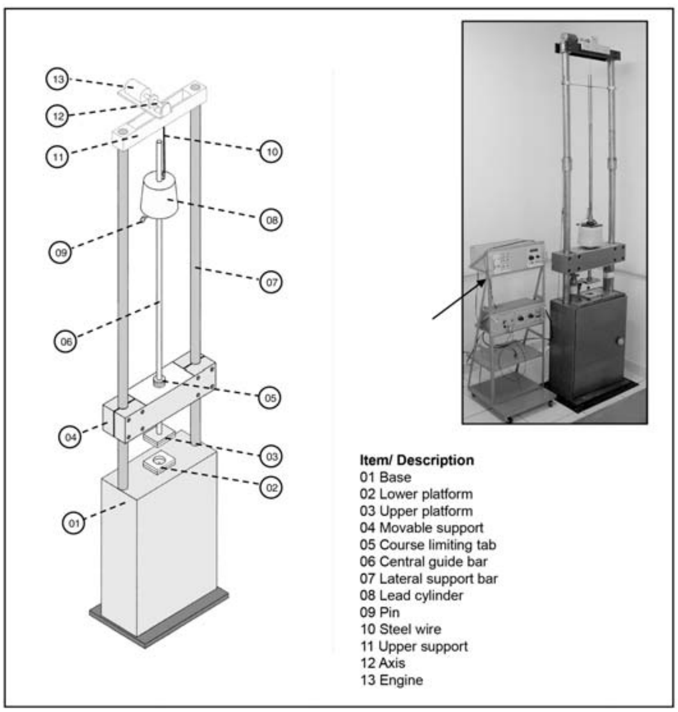


***Figure 2 -*** *Device built for producing fractures.*

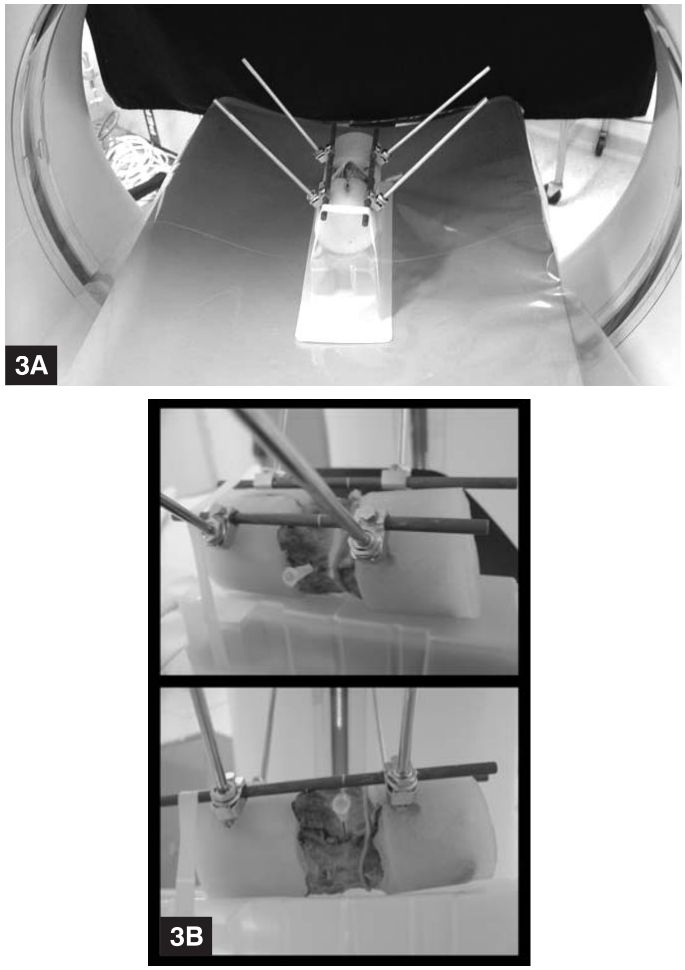


***Figure 3 -*** *Vertebral segment fixated with internal fixator and positioned for computed tomography scan (a). Please, not the image level marked with hypodermal needle to achieve the same level (b).*

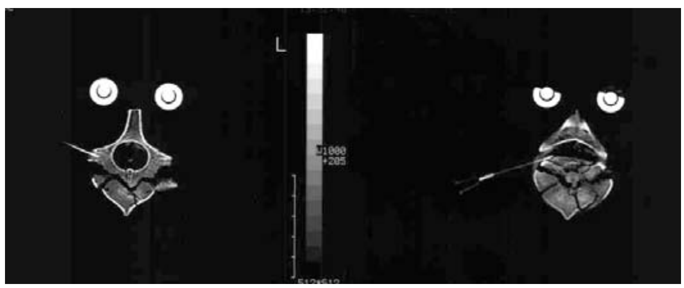


***Figure 4 -*** *Computed tomography scan of a fractured vertebra illustrating vertebral canal compression.*

The assessment with computed tomography scan was performed after each separate ligamentotaxis maneuver (lordosis or distraction) and after both maneuvers conjunctively (lordosis + distraction or distraction + lordosis).

After ligamentotaxis maneuvers and vertebral canal width measurement, the components of the fixation system were loosened, and the axial compression force applied on the vertebral segment until fractured vertebral body height was restored. Then, a new computed tomography scan was performed for assessing vertebral canal width and a new ligamentotaxis maneuver was performed, with different maneuver sequences from the one first performed (Figure 5). For capturing the same tomography image at the same place, a hypodermal needle was employed to mark the exact site

(Figure 3). The difference of the vertebral canal width measurement after a maneuver indicated the displacement produced by that maneuver on the fractured vertebral body fragment.

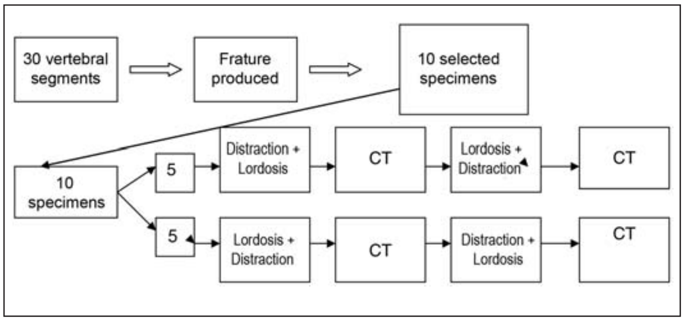


***Figure 5*** *- Schematic illustration of the experiment steps.*

The values obtained from measurements of the vertebral canal width on the computed tomography images after performing different ligamentotaxis maneuvers have been assessed by the Shapiro-Wilk's test to evaluate sample normality. The comparison of the results of the different ligamentotaxis maneuver sequences (lordosis + distraction and distraction + lordosis) was made by using the Student's t-test, with a significance level of 5% ($p<0.05$).

## RESULTS

Fractured vertebrae selected for this study showed a shorter vertebral body after fracture production, ranging from 6 to 8 mm (average: 7 mm). (Figure 6 and Table 1).

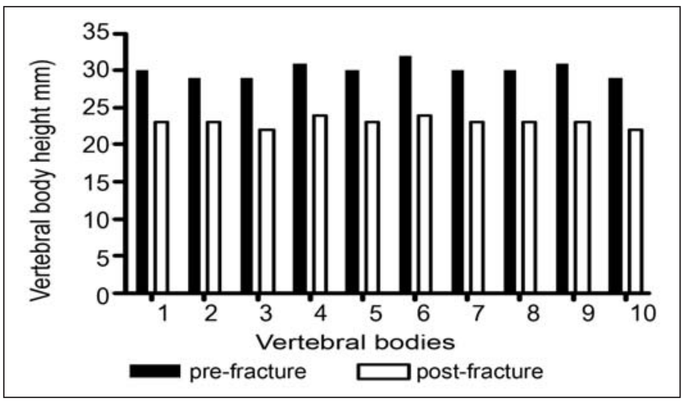


***Figure 6*** *- Vertebral body height before and after fracture.*

***Table 1*** *– Vertebral body height in millimeters*

| Vertebrae | I | II | III | IV | V | VI | VII | VIII | IX | X |
|---|---|---|---|---|---|---|---|---|---|---|
| Original Height | 30 | 29 | 29 | 31 | 30 | 32 | 30 | 30 | 31 | 29 |
| Fractured Height | 23 | 23 | 22 | 24 | 23 | 24 | 23 | 23 | 23 | 22 |

The comparison of vertebral canal widths previously and subsequently to ligamentotaxis showed a statistically significant difference ($p< 0.001$) pointing out that the ligamentotaxis maneuver was effective for vertebral canal decompression in all sequences performed, and also on the specimens having its height restored. Tables 2 and 3, and Figures 7 and 8 show the values achieved with the different sequences of maneuvers in the specimens. Vertebral canal decompression was seen considering initial ligamentotaxis maneuver or its performance on the restored specimen. The comparison of the overall result of vertebral canal decompression showed a statistical difference ($p<0.001$) with initial values for both kinds of sequences performed, indicating the occurrence and effectiveness of ligamentotaxis for vertebral canal decompression on the employed model.

***Table 2*** *- Measurements of vertebral canal's anteroposterior width and displacement of fractured vertebral body's fragment on specimens which the sequence lordosis + distraction was applied on the fractured vertebra and on the vertebra with reconstructed fracture.*

| | Vertebrae | Pre-maneuver Original (mm) | Post-maneuver Lordosis (mm) | Post-maneuver Lor+Dist (mm) | Fragment displacement (mm) |
|---|---|---|---|---|---|
| Original fractures | II | 9.0 | 10.0 | 12.0 | 3,0 |
| | IV | 5.0 | 7.0 | 8.0 | 3,0 |
| | VI | 5.0 | 6.0 | 7.0 | 2,0 |
| | VIII | 7.0 | 10.0 | 11.0 | 4,0 |
| | X | 5.0 | 9.0 | 9.0 | 4,0 |
| | Mean | 6.2 | 8.4 | 9.4 | 3,2 |
| | SD | 1.8 | 1.8 | 2.1 | 0,8 |
| Restored fractures | I | 8.0 | 9.0 | 10.0 | 2,0 |
| | III | 9.0 | 11.0 | 13.0 | 4,0 |
| | V | 6.0 | 8.0 | 10.0 | 4,0 |
| | VII | 6.0 | 8.0 | 10.0 | 4,0 |
| | IX | 11.0 | 12.0 | 12.0 | 1,0 |
| | Mean | 8.0 | 9.6 | 11.0 | 3,0 |
| | SD | 2.1 | 1.8 | 1.4 | 1,4 |
| **Mean** | | **7.1** | **9.0** | **10.2** | **3.1** |

***Table 3*** *- Measurements of vertebral canal anteroposterior width and fractured fragment displacement on the specimens which the sequence distraction + lordosis was applied on the fractured vertebra and on the vertebra with reconstructed fracture.*

| | Vertebrae | Pre-maneuver Original (mm) | Post-maneuver Distraction (mm) | Post-maneuver Dis+Lor (mm) | Fragment displacement (mm) |
|---|---|---|---|---|---|
| original fractures | I | 9.0 | 8.0 | 8.0 | -1,0 |
| | III | 8.0 | 9.0 | 12.0 | 4,0 |
| | V | 7.0 | 8.0 | 9.0 | 2,0 |
| | VII | 6.0 | 8.0 | 9.0 | 3,0 |
| | IX | 11.0 | 11.0 | 11.0 | 0,0 |
| | Mean | 8.2 | 8.8 | 9.8 | 1,6 |
| | SD | 1.9 | 1.3 | 1.6 | 1,8 |
| restored fractures | II | 8.0 | 10.0 | 10.0 | 2,0 |
| | IV | 5.0 | 7.0 | 7.0 | 2,0 |
| | VI | 5.0 | 7.0 | 6.0 | 1,0 |
| | VIII | 6.0 | 7.0 | 7.0 | 1,0 |
| | X | 8.0 | 9.0 | 8.0 | 0,0 |
| | Mean | 6.4 | 8.0 | 7.6 | 1,2 |
| | SD | 1.5 | 1.4 | 1.5 | 0,8 |
| **Mean** | | **7.3** | **8.4** | **8.7** | **1.4** |
| **SD** | | **1.9** | **1.3** | **1.9** | **1.3** |

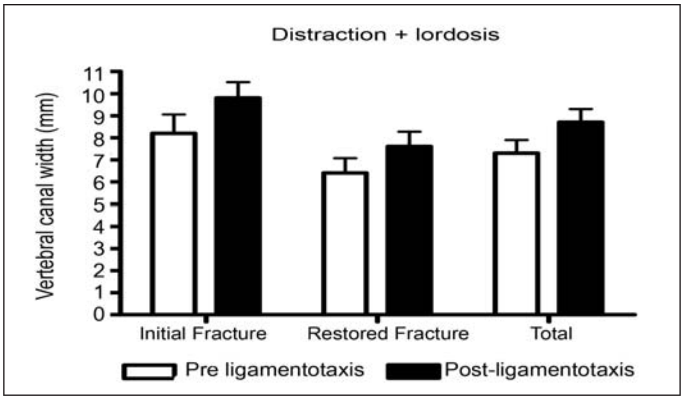


*Figure 7 - Vertebral canal decompression on the vertebral segment group in which distraction + lordosis was employed during ligamentotaxis.*

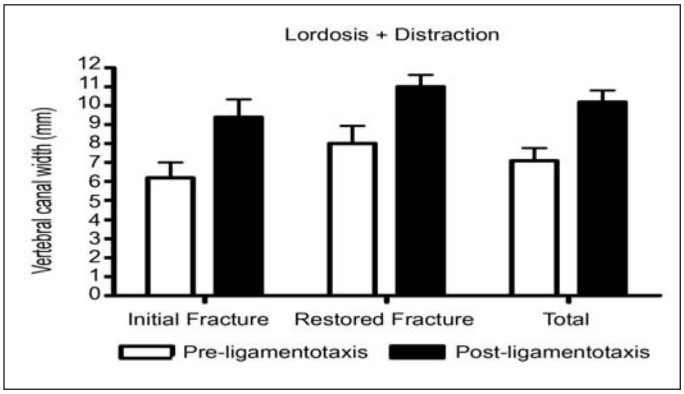


*Figure 8 - Vertebral canal decompression on the vertebral segment group in which lordosis + distraction was employed during ligamentotaxis.*

The comparison of displacement results achieved by distraction + lordosis maneuver to the lordosis + distraction maneuver did not show statistically significant difference (p=0.06). Percent data analysis showed a difference between both methods, and, although no statistically significant difference had been notice, the value found was very close to the significance level adopted in the study (p≤0.05). Such proximity suggests a trend for a better correction when lordosis + distraction is performed. The increased vertebral canal width in the distraction + lordosis maneuver was 19.2%, and 43.7% for lordosis + distraction maneuver. The values for vertebral body's fractured fragment displacement on the fractured specimens (restored and total sample) can be seen on Figure 9.

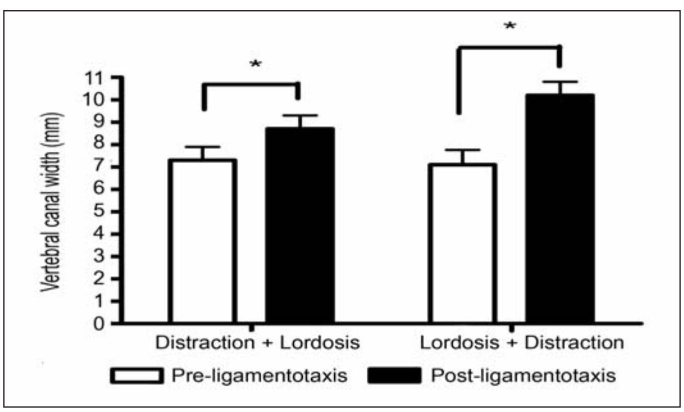


*Figure 9 - Comparison of the results of both maneuver sequences. Please, note that a statistically significant difference was found (*) between vertebral canal width values before and after ligamentotaxis, but no statistical difference was seen between both maneuver sequences.*

## DISCUSSION

Ligamentotaxis is an alternative for vertebral canal decompression and presents the advantage of not requiring additional approach (anterior or posterolateral) of the vertebral segment to decompress nervous structures compressed by bone fragments of the vertebral body's posterior wall. Ligamentotaxis must be made as early as possible, with better results seen within four days after trauma[7-9].

Ligamentotaxis is directly related to posterior longitudinal ligament tensioning, which produces the repositioning of a vertebral body's fractured fragment. PLL insertion is done at the intersection between disc and vertebral body, and, at that site, PLL presents with lateral protuberances. On the medium portion of vertebral body, this ligament is found some millimeters away from the vertebral body's posterior wall at the level of the feeding foramen. As a result of this anatomical feature, vertebral body's fragments with retropulsion on vertebral canal and causing < 35% compression cannot be reduced by applying distraction forces on the order of 150N[6]. In very serious injuries in which only the posterior annulus wall and the PLL remain intact, a lower reduction strength is generated by this ligament[6,8]. The connection between disc and fractured bone fragment is very important, with fragment reduction not occurring when the fractured vertebral body's fragment loses its connection to the disc, although PLL maintains its integrity. This connection represents an additional mechanism of reduction, which helps on reducing bone fragments and seems to be correlated to the anatomical reduction of the injury, and not to distraction[6].

Performing ligamentotaxis with the use of an internal fixator implies on performing lordosis and distraction maneuvers, and lordosis prior to distraction is being currently recommended. Although the technical recommendation of this sequence, we didn't find studies in literature comparing the sequencing of these maneuvers.

Ligamentotaxis is closely related to the treatment of burst-like fractures presenting intact posterior ligament elements. The isolated correction of kyphosis on a fractured vertebral segment does not allow vertebral canal decompression, and the application of distraction forces promoted ligamentotaxis[5]. The application of distraction forces before or after kyphosis correction is the key element for performing ligamentotaxis and vertebral canal decompression[5,8]. Our results confirm this finding, but the sequence in which maneuvers are performed may lead to different results. Despite of not having found a statistical difference, it seems that when lordosis is provided first, canal decompression is enhanced.

Applying distraction only does not present any advantage, and its performance by means of long instrumentation causes the rectification of physiological curves of the vertebral spine[8]. The results achieved in this study showed that adding a lordosis maneuver, either before or after distraction maneuver, has contributed to an additional vertebral canal decompression. There are reports on better clinical outcomes with lordosis on Harrington's nails employed for that purpose[10].

The results found in our experimental study confirm the report by Zou et al.[8], where they state that the distraction maneuver alone is responsible for restoring vertebral body height, and that vertebral canal decompression by means of ligamentotaxis shows better results when associated to lordosis maneuvers.

We must also consider that vertebral canal decompression does not exclusively occur because of ligamentotaxis effects. The effect of tensioning all soft parts inserted on the vertebra, including the anterior longitudinal ligament and the fibrous annulus, also take part of fragments repositioning[5]. This finding corroborates the lordosis maneuver associated to distraction, which is consistent to the results we found in this experiment.

The experimental model employed here deserves some considerations, and the use of swine vertebrae reflects the challenges in obtaining human cadaver vertebrae. The interpretation of the results must take into account the potential anatomical differences between human and swine vertebrae. However, the posterior longitudinal ligament insertion pattern is very similar, and the essential phenomenon of ligamentotaxis may be studied in this experimental model.

The statistical analysis of our results didn't show differences between both ligamentotaxis maneuver sequences. However, the significance level achieved in the comparison was very close to the adopted one, suggesting a strong trend that lordosis being performed prior to distraction in ligamentotaxis would have a better potential for vertebral canal decompression.

## CONCLUSION

The comparison of ligamentotaxis maneuvers sequences (lordosis + distraction versus distraction + lordosis) did not show statistically significant differences concerning vertebral canal decompression, but suggested that the best sequence is the one starting with lordosis.

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