

CORRECTION OF THE SPINAL SAGITTAL PLANE: THE APPLICATION OF CONVERGENT OR DIVERGENT SCREWS

CORREÇÃO DO PLANO SAGITAL DA COLUNA VERTEBRAL: APLICAÇÃO DE PARAFUSOS CONVERGENTES OU DIVERGENTES

CORRECCIÓN DEL PLANO SAGITAL DE LA COLUMNA VERTEBRAL: APLICACIÓN DE TORNILLOS CONVERGENTES O DIVERGENTES

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ABSTRACT

Objective: To present a new principle for correction of the sagittal plane of the spine through the convergent or divergent placement of monoaxial pedicle screws in this plane, associated with compression or distraction, to provide lordotizing or kyphotizing leverage force. **Method:** A statistical mechanical study of twenty-eight fixations in synthetic spine segments was performed. In fifteen pieces, pedicle screws were applied to the ends of the segments with positioning convergent to the center of the fixation. They were attached to the straight rods and subjected to compression force. The other thirteen segments were fixed with pedicle screws in a direction divergent to the center of the fixation, attached to the straight rods, and subjected to distraction force. **Results:** To create kyphosis in the 15 synthetic segments of the spine, the mean pre-fixation Cobb angle was -0.7° and the mean post-fixation angle was $+15^\circ$. To create lordosis in the 13 segments, the mean pre-fixation Cobb angle was $+1^\circ$ and the mean post-fixation angle was $+18^\circ$. The difference was confirmed by statistical mechanical tests and considered significant. However, there is no relevant difference between the mean angles for lordosis and kyphosis formation. **Conclusions:** It was concluded that the correction of the sagittal plane of the spine by applying the new instrumentation method is efficient. A statistical mechanical test confirmed that the difference in Cobb degrees between pre- and post-fixation of the synthetic spine segments was considered significant in the creation of both kyphosis and lordosis. **Level of evidence II C; Statistical mechanical study of synthetic spine segments.**

Keywords: Lordosis; Kyphosis; Surgical Fixation Devices; Rotation.

RESUMO

Objetivo: Apresentar um novo princípio para correção do plano sagital da coluna vertebral, posicionando os parafusos pediculares monoaxiais nesse plano de forma convergente ou divergente, associados à compressão ou distração, para proporcionar força em alavanca lordotizante ou cifotizante. **Métodos:** Realizou-se um estudo de mecânica estatística de 28 fixações em segmentos de coluna sintética. Em quinze peças, foram aplicados parafusos pediculares monoaxiais nos extremos dos segmentos abordados com posicionamento no sentido convergente à fixação. Foram agregados às hastes retas e submetidos à força de compressão. Em outros treze segmentos, a fixação foi feita com parafusos pediculares monoaxiais, no sentido divergente ao centro da fixação, integrados às hastes retas e submetidos à força de distração. **Resultados:** Para criar cifose nos 15 segmentos sintéticos da coluna vertebral, a média do ângulo de Cobb na pré-fixação foi de $-0,7^\circ$ e a média pós-fixação foi de $+15^\circ$. Para criar lordose em 13 segmentos, a média do ângulo de Cobb na pré-fixação foi de $+1^\circ$ e a média pós-fixação foi de $+18^\circ$. A diferença foi confirmada por testes de mecânica estatística e considerada significativa. Contudo, não existe diferença relevante entre os ângulos médio para formação da lordose e da cifose. **Conclusões:** Conclui-se que a correção do plano sagital da coluna aplicando o novo método de instrumentação é eficiente. Confirmou-se com teste de mecânica estatística que a diferença em graus de Cobb entre o período pré e o pós-fixação dos segmentos de coluna sintética fixados foi considerada significativa, tanto na criação da cifose quanto da lordose. **Nível de evidência II C; Estudo mecânico estatístico de segmentos de coluna sintética.**

Descritores: Lordose; Cifose; Dispositivos de Fixação Cirúrgica; Rotação.

RESUMEN

Objetivo: Presentar un nuevo principio para corrección del plano sagital de la columna vertebral, posicionando los tornillos pediculares monoaxiales en ese plano de forma convergente o divergente, asociados a la compresión o distracción, para proporcionar fuerza en palanca lordotizante o cifosante. **Métodos:** Se realizó un estudio de mecánica estadística de 28 fijaciones en segmentos de columna sintética. En quince piezas, fueron aplicados tornillos pediculares monoaxiales en los extremos de los segmentos abordados con posicionamiento en el sentido convergente a la fijación. Fueron agregados a las varillas rectas y sometidos a la fuerza de compresión. En otros trece segmentos, la fijación fue hecha con tornillos pediculares monoaxiales, en el sentido divergente del centro de la fijación, integrados a las varillas rectas

Study conducted at the Instituto da Coluna Vertebral BH.

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y sometidos a la fuerza de distracción. Resultados: Para crear cifosis en los 15 segmentos sintéticos de la columna vertebral, el promedio del ángulo de Cobb en la prefijación fue de $-0,7^\circ$ y el promedio de postfijación fue de $+15^\circ$. Para crear lordosis en 13 segmentos, el promedio del ángulo de Cobb en la prefijación fue de $+1^\circ$ y el promedio de postfijación fue de $+18^\circ$. La diferencia fue confirmada mediante tests de mecánica estadística y considerada significativa. Sin embargo, no existe diferencia relevante entre los ángulos promedios para la formación de lordosis y de cifosis. Conclusiones: Se concluye que la corrección del plano sagital de la columna aplicando el nuevo método de instrumentación es eficiente. Se confirmó con test de mecánica estadística que la diferencia en los grados de Cobb entre el período de pre y postfijación de los segmentos de columna sintética fijados fue considerada significativa, tanto en la creación de cifosis como de la lordosis. **Nivel de evidencia II C; Estudio mecánico estadístico de segmentos de columna sintética.**

Descriptor: Lordosis; Cifosis; Dispositivos de Fijación Quirúrgicos; Rotación.

INTRODUCTION

The literature refers to Scheuermann's kyphosis as a structural pathology of the lumbar or thoracolumbar spine that affects 0.4 to 8.3% of the general population for which there are numerous diagnostic hypotheses.¹

Dickson confirmed that a loss of thoracic kyphosis may precede the development of deformity and vertebral rotation.²

Winter and Nash reported that thoracic hypokyphosis was responsible for the reduction of pulmonary function in patients diagnosed with adolescent idiopathic scoliosis (AIS).^{3,4}

Even though spinal alignment has been assessed only in the coronal plane for many years, several publications highlight the importance of changes in the sagittal plane. The authors also highlight the relationship of the spine with changes in pelvic orientation and how they determine vertebral alignment as a whole.⁵⁻⁹

Pelvic Incidence (PI): The angle between the line perpendicular to the midpoint of the sacral plateau and a line that connects this point to the central axis of the femoral head, from 40° to 65° considered normal. Sacral Slope (SS): The angle between a line in the upper plateau of S1 and a horizontal line, parallel to the ground, normal being from 30° to 50° . Pelvic Tilt (PT): The angle between a line that connects the midpoint of the sacral plateau to the axis of the femoral head and a vertical line, perpendicular to the ground, from 10° to 25° considered normal.^{10,11}

For decades, the main focus of surgical treatment for AIS was the amount of correction in the coronal plane, however, correction in the sagittal plane and vertebral rotation have also been recognized as being almost as important as coronal correction. The authors note the difficulties in correcting vertebral rotation and hypokyphosis together.¹²

A series of 76 patients with AIS, especially Lenke type I, was studied. The indices and spinopelvic parameters were compared before and after posterior approach surgical correction. A slight imbalance was observed in the sagittal plane of the spine, mainly in the cases that presented previous hypokyphosis, however they stated that more studies are necessary.¹³

To evaluate and determine the efficacy of several configurations of forces in the correction of three-dimensional spinal deformities, a 3D model of the spine was developed based on computed tomography images obtained from a scoliotic girl. The model was exported to Abaqus software to verify the effects of several configurations of force and magnitudes in the correction of spinal curvatures. The vertically directed forces reduced the scoliotic, lordotic, and kyphotic curves. Using a combination of transversal and vertical forces was recommended to reduce the scoliotic curve without significant collateral effects in the sagittal plane.¹⁴ The objective of the article is to present a new principle for the correction of the spinal sagittal plane, placing the monoaxial pedicle screws in this plane, either convergent or divergent, associated with compression or distraction, to provide lordotizing or kyphotizing leverage force.

METHODS

A statistical mechanical study of the instrumentation of 28 segments (two vertebrae and one disc) of a synthetic spine was conducted.

In 15 of them, monoaxial pedicle screws were applied at the ends of segments, positioned in the direction convergent to the

fixation. They were connected to the straight rods. Subsequently, compression force was applied, with the objective of promoting leverage, rotation of the vertebrae in the sagittal plane, and correction of segmental kyphosis, considering that the monoaxial screws lock at 90° when the rods are adjusted. (Figure 1)

Likewise, 13 segments of synthetic spine were fixed with screws, this time in the divergent direction in relation to the center of the fixation, connected to the straight rods, and associated with distraction in order to promote leverage, rotation of the vertebrae in the sagittal plane, and correction of segmental lordosis. (Figure 2)

Reference points for screw entry: Monoaxial pedicle screws are introduced in alignment with the pedicles. In the sagittal plane, they are placed divergently in relation to the head, 5 mm above the upper line of the transverse processes in the thoracic spine and on this line in the lumbar spine. The screws are applied convergently in relation to the head in the midline of the transverse processes in the thoracic spine and in the lower line of these processes in the lumbar spine. (Figure 3)

Figure 4 shows the instrumentation of the synthetic spine. In the upper left the monoaxial pedicle screws were placed in the convergent

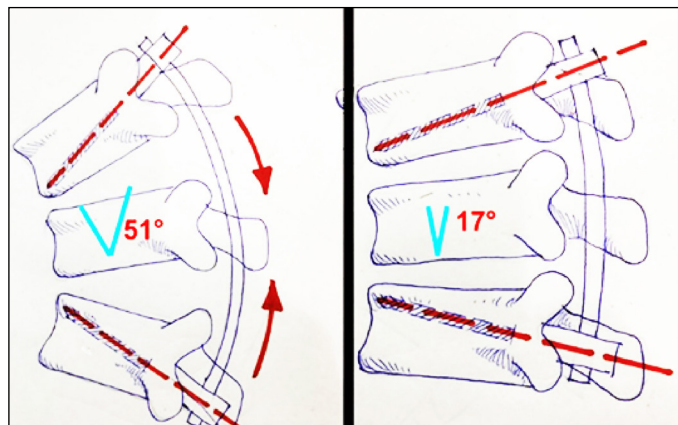


Figure 1. Convergent screws, associated with compression force.

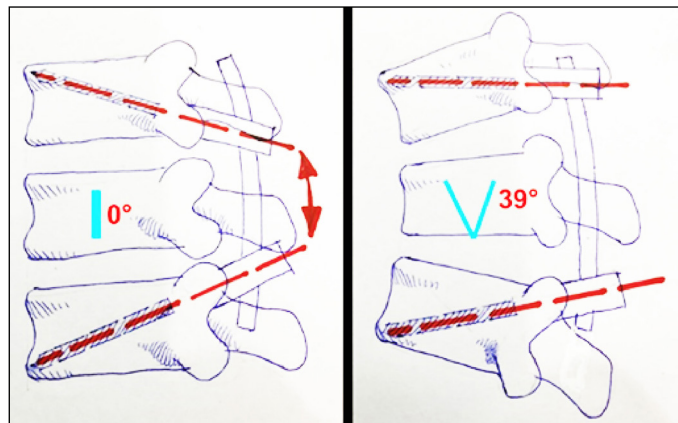


Figure 2. Divergent screws, associated with distraction force.

direction in relation to the disc and compression was applied with a straight rod. On the upper right, the screws were placed divergently to the disc and distraction was applied. In the image at the lower left, the formation of 12° lordosis and the rupture of the anterior longitudinal ligament can be observed. On the lower right, kyphosis of 14° and rupture of the posterior longitudinal ligament were created.

In each fixed synthetic spine segment a positioning in relation to the sagittal plane was observed. Photographs were taken and the pre- and post-fixation kyphosis and lordosis angle values measured using the Cobb method were collected. A spreadsheet was created and submitted to the statistical study.

For the evaluation of the differences between the pre-fixation and post-fixation values of the 28 fixed synthetic spine segments, Wilcoxon's non-parametric test was used for kyphosis and lordosis since the data did not follow degree distribution.

For the comparison of the pre- and post-fixation angles of kyphosis and lordosis as measured by the Cobb method, the Mann-Whitney test for independent samples was used.

The study data were analyzed using the PASW statistical program, version 18. In all of the statistical tests conducted, a significance level of 5% was considered. Thus, associations with p-value less than 0.05 were considered statistically significant.

The project was exempted from approval by Plataforma Brasil because it did not involve experimentation on human beings.

RESULTS

From what was confirmed in the statistical mechanical test, the difference in degrees between the pre- and post-fixation Cobb

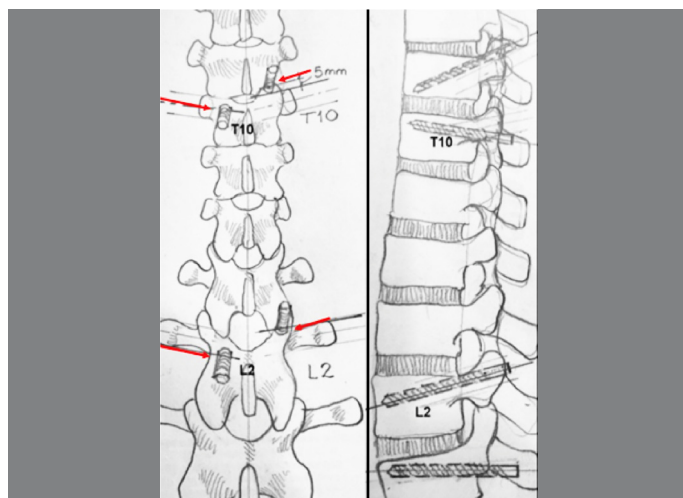


Figure 3. Screw entry in the coronal and sagittal planes.

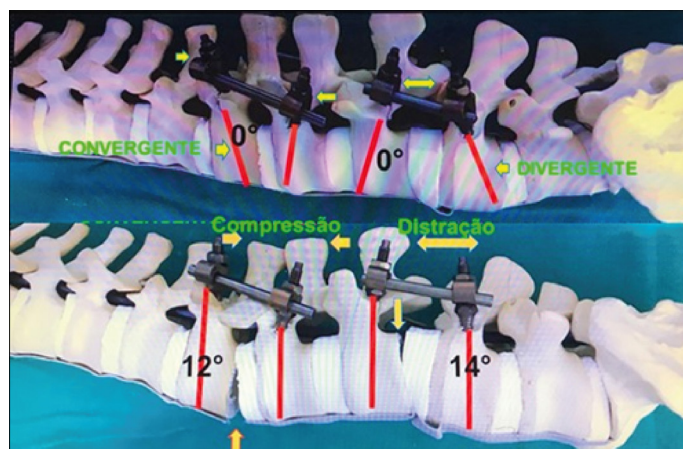


Figure 4. Fixation of the synthetic spine.

measurements of the synthetic spine segments was considered significant both for kyphosis and lordosis. (Table 1 and Figure 5)

According to the results in Table 2, using the Mann-Whitney test there was no statistical difference between the increase in the angles in lordosis and kyphosis.

Exhibits of cases with disturbances in the alignment of the sagittal plane of the spine, submitted to correction using convergent, divergent, and neutral screws in relation to the apex of the curvature.

DISCUSSION

For years, we have lived with the pulling out and loosening of screws at the apex of the concave side of rigid lordoscoliosis and also in the distal part of the fixation in the correction of severe thoracolumbar kyphosis. In the case of hyperkyphosis, the loosening was noted mainly when the distal screws of the fixation were placed in positions divergent from the head and even in the neutral position. (Figures 6 and 8)

Over the last 4 years, we began to observe that in hyperkyphosis correction when we placed the monoaxial screws of the distal part converging towards the head it caused leverage, leading to rotation of the distal vertebrae of the fixation in the sagittal plane without pullout and with good kyphosis correction.

Currently, the gold standard for correction of three-dimensional spinal deformities is posterior instrumentation, fusion, and the application of pedicle screws. Although initially achieving maximum

Table 1. Descriptive statistics of the 15 fixations to create kyphosis and the 13 instrumentations to create lordosis, according to the degrees of the angles as measured by the Cobb method.

Variable	Pre	Post	P-value
Promote kyphosis			
N	15	15	0.003**
Mean (SD)	-0.733° (7.69)	15.7° (7.57)	
Median [Min, Max]	-2.00° [-12.0, 21.0]	12.0° [5.00, 29.0]	
Create lordosis			
N	13	13	0.002**
Mean (SD)	1.00° (5.66)	18.3° (7.48)	
Median [Min, Max]	2.00° [-12.0, 12.0]	19.0° [8.00, 29.0]	

Note: The probability of significance (p-value) refers to Wilcoxon's test for paired samples.

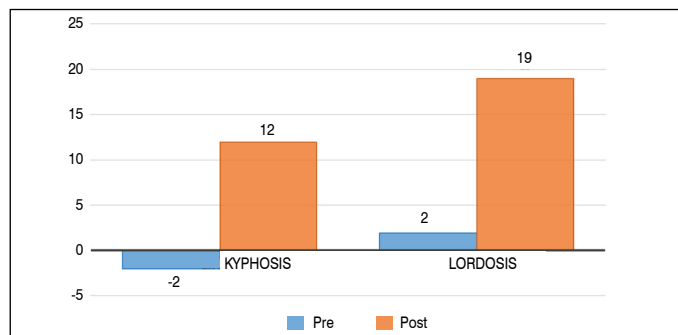


Figure 5. Frequency distribution of the 28 fixed spinal segments (15 to create kyphosis and 13 to create lordosis) for each method, measured according to the Cobb angle.

Table 2. Evaluation of the differences between pre- and post-fixation for lordosis and kyphosis.

Variable	Difference in kyphosis between pre and post	Difference in lordosis between pre and post	P-value
n	15	13	0.367
Mean (SD)	14.9° (9.28)	18.4° (10.2)	
Median [Min, Max]	12.0° [-1.00, 32.0]	16.0° [1.00, 31.0]	

Note: - The probability of significance (p-value) refers to the Mann-Whitney test for independent samples.

correction in the coronal planes was not the focus, more recent techniques have been centered on three-dimensional balance and correction in the coronal, sagittal, and axial planes.¹³ Karimi et al., recommend using a combination of transversal and vertical forces to correct scoliosis without significant collateral effects in the sagittal plane.¹⁴ Regarding the sagittal plane, monoaxial screws, when adjusted to the rods, lock at 90°. Therefore, depending on their convergent or divergent positioning, vertebral rotation will occur,

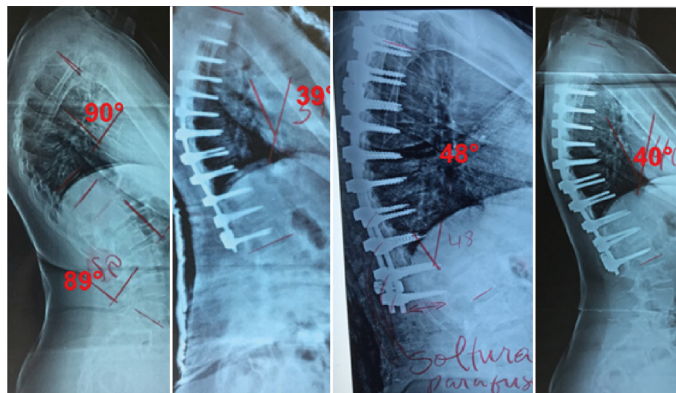


Figure 6. Female patient, 19 years of age. In the radiological image on the left, thoracic kyphosis of 90°, a sequela of Scheuermann's disease is seen. Submitted to correction with osteotomies and pedicular fixation of T1 to L1 with monoaxial screws, the distal screws being slightly divergent, the kyphosis was corrected to 39°, as seen in the second X-ray. After 15 days there was a loosening of the 8 distal screws with a loss of correction to 48°, observed in the third image. In the X-ray on the right, the final result following revision surgery, including vertebra L2 and totaling 26 screws, can be observed.

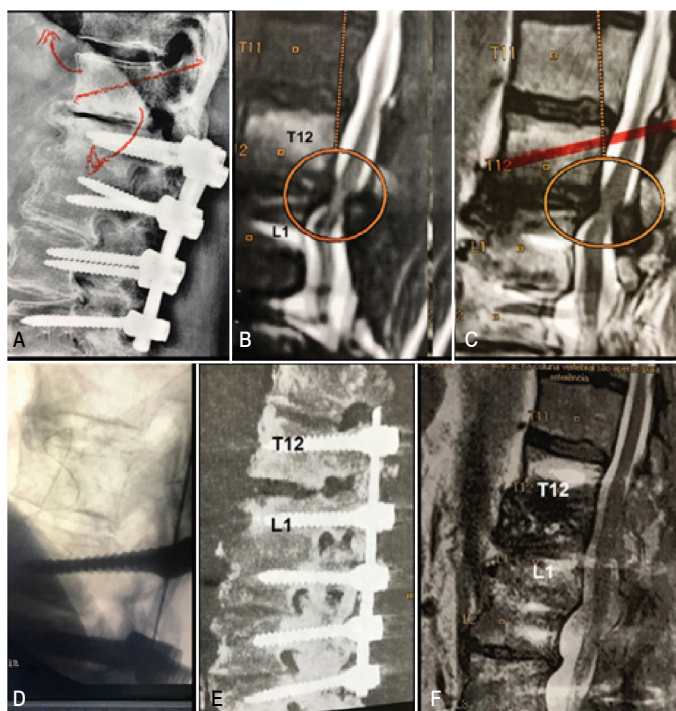


Figure 7. Male patient, 74 years of age, who underwent fixation from L1 to L4 in another service (A). He had osteopenia, instability, stenosis, 360° medullary compression in T12/L1, myelomalacia, marked acute paraparesis, and it was impossible for him to walk (B and C). The instrumentation was changed to fixation, including T12, with pedicle screws converging toward the lesion (D). A laminectomy and resection of the yellow ligament were performed. Leverage and rotation of T12 occurred (E), providing a reduction of the disc protrusion in T12/L1 through ligamentotaxis, medullary decompression (F), and sudden neurological recovery.

pertinent or not. In view of this observation, the authors of this article opted to conduct a statistical mechanical study of the synthetic spine segments.

In Figure 4, the occurrence of vertebral rotation from the leverage force from the convergent or divergent assembly of the monoaxial screws can be seen, results that were repeated in the 28 synthetic spine segment assemblies, showing the possibility of positive contributions to the correction of hyperkyphosis and hyperlordosis.

In the literature one can find many articles about mechanical and statistical tests conducted in laboratories of reference, by renowned and reputable researchers, analyzing the possibility of reducing the pullout of screws from the vertebrae, among which are included studies of the pilot hole diameter, double-core screws, cylindrical screws, bicortical screws, multicortical implants, pilot hole tapping, anti-rotational torque, and screw cap and slot design.^{15,20} All these precautions to prevent the screws from pulling out are valid, however, the leverage principle does not exert traction on the screw in the pullout direction, but rather impacts it against the vertebral body, which makes the difference.

La Maida et al. conducted a study showing a slight imbalance of the sagittal plane of the spine in patients operated for Lenke type I AIS, especially in cases with previous hypokyphosis.¹²

Considering that the molding of the rods in physiological kyphosis for the correction of thoracic lordoscoliosis almost always ends in loosening of the apical screws and non-correction of the hypokyphosis.

Correcting scoliosis associated with hypokyphosis is a real challenge. Therefore, the application of divergent screws on the concave side of the curvature at the ends of the fixation associated with distraction and normally positioned screws submitted to compression on the convex side is suggested, as the formation of kyphosis was observed in one hundred percent of the synthetic spinal segments fixed in the present study (See Figure 4, images on the right.).

The authors state that the current literature no longer supports the tendency to preserve movement with selective fusion. They prioritize sagittal alignment despite possible arthrosis resulting from extensive fusions.²¹ We believe this is really a priority.

Martiniani et al. presented a retrospective analysis of 219 patients with thoracolumbar spine fractures who were instrumented with transpedicular fixation with normally positioned screws, which is the gold-standard procedure for this. However, the long-term results showed cases of progressive disc collapse.²² It is a frequently observed complication. (Figure 8) The possibility of positioning convergent screws in the ends of the fixation is suggested.

The surgeons of this article observed cases of thoracic hyperkyphosis operated using convergent screws showing very satisfactory

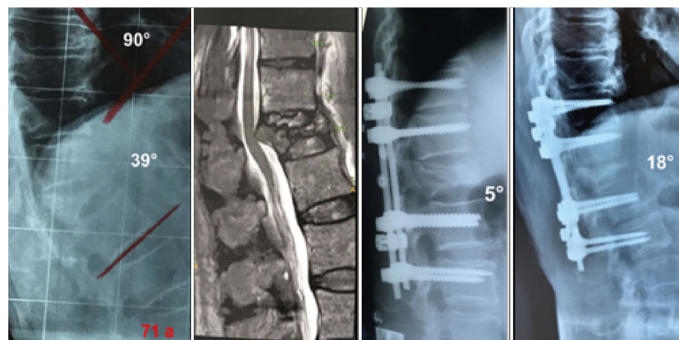


Figure 8. Male patient, 71 years of age, who fell from his own height. The radiographic image on the left shows an L1 fracture with kyphosis of 39° that occurred one month before. The magnetic resonance to the right shows a retropulsed bone fragment. In the radiograph in the center, the spine fixed with normally positioned monoaxial screws and the partial disimpaction of the L1 vertebral body can be observed. In the image on the right, loosening of the distal screws and loss of correction and height of L1 can be observed.

results. (Figures 7, 9, 10, 11, 12 and 13) However, in the correction of hyperkyphosis using normally positioned screws and screws divergent to the curve, loosening of the screws and poor correction of the deformity were observed. (Figures 12 and 13)

The authors did not observe new types of complications with convergently or divergently placed screws in the treatment of deformity, but they did observe improved correction in the sagittal plane. This new instrumentation principle undoubtedly requires additional training. The risk of screws introduced in a direction convergent to the head touching the nerve roots in the foramina is real, however, with intraoperative neurological monitoring this is controlled.

It is expected that the possibility of causing leverage and vertebral rotation in the sagittal plane with monoaxial screws implanted convergently or divergently will reduce the loosening of screws, with better prospects for fixation of osteopenic bone, shorter fixations, and the preservation of vertebral mobility.

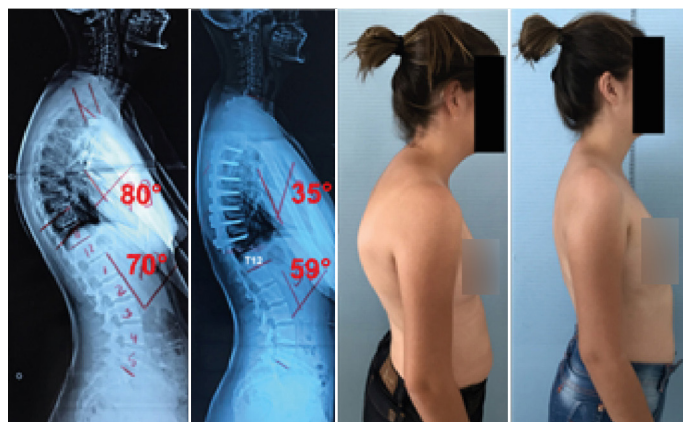


Figure 9. Female patient, 21 years of age, operated 1 year ago. Image on the left – presence of rigid thoracic hyperkyphosis of 80°. In the X-ray on the right fixation of T1 to T11 is observed, with long screws positioned convergently to the apex of the curvature. On the right, pre- and postoperative photos.

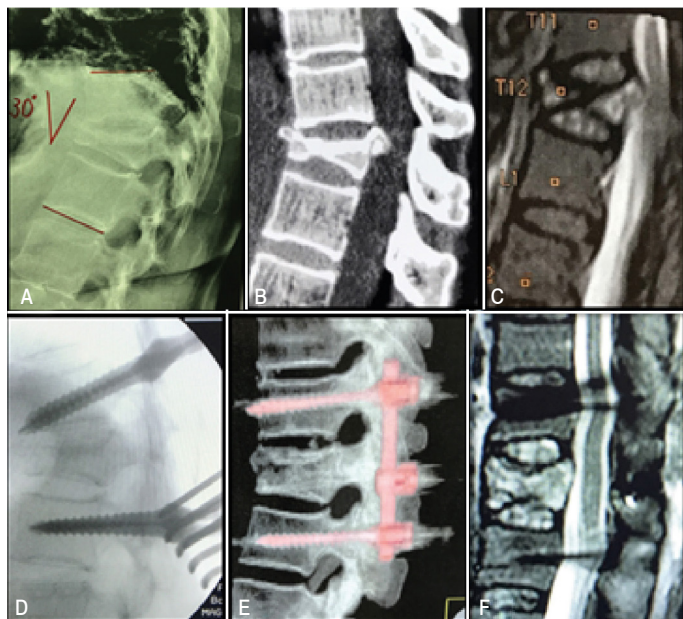


Figure 10. Female patient, 74 years of age, recent spinal fracture, local kyphosis of 30° (A), retropulsed fragment in the vertebral canal (B), presence of spinal cord edema (C). The screws of the upper end were positioned in a direction convergent to the lesion (D), aggregated to the straight rods (D). Leverage force and vertebral rotation in the sagittal plane were promoted and satisfactory correction of the lesion and decompression via ligamentotaxis of the spinal cord occurred (F).

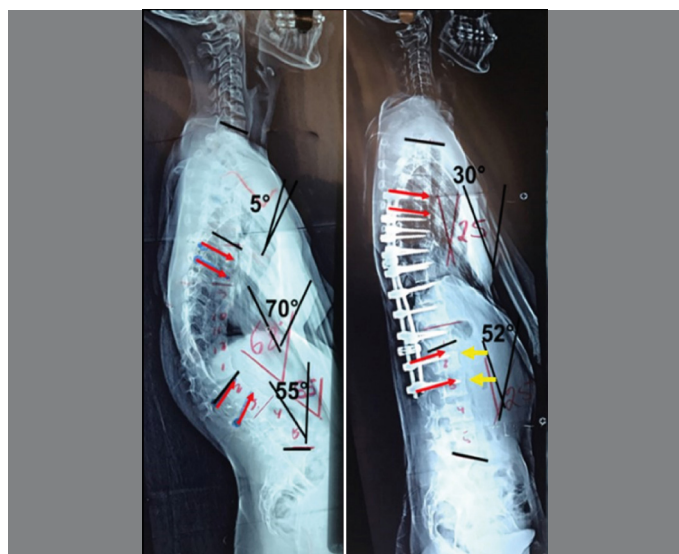


Figure 11. Panoramic radiograph (X-ray) showing correction of kyphosis using screws at the ends of the fixation convergent to the apex of the curvature.

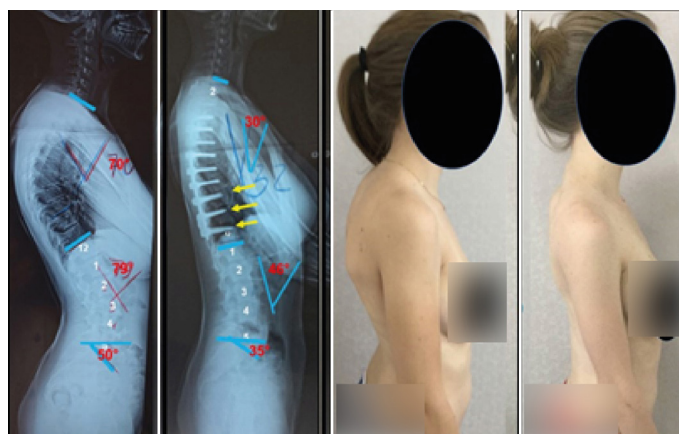


Figure 12. Female patient, 17 years of age, operated about 4 years ago for thoracic hyperkyphosis of 70°. Right X-ray – screws distal to the fixation placed in position convergent to the apex of the curvature. Leverage, vertebral rotation, and correction of the deformity occurred. Pre- and postoperative photos on the right.

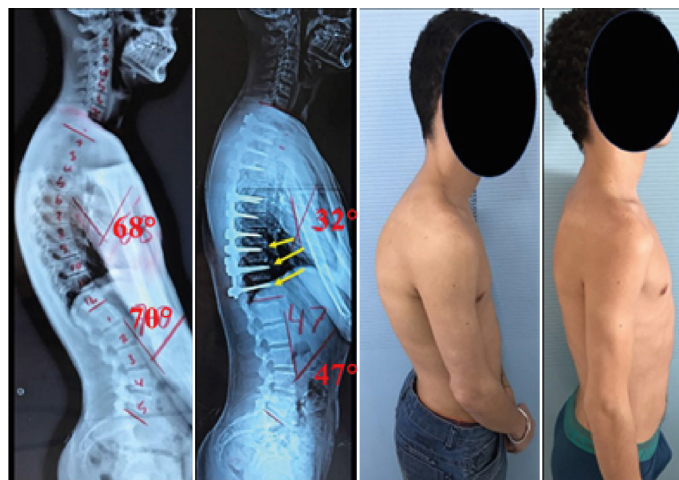


Figure 13. Male patient, 18 years of age, operated one year ago for thoracic hyperkyphosis of 68°. X-ray on the right shows instrumentation from T2 to T11, screws distal to the fixation placed in a position convergent to the apex of the curvature. Leverage, vertebral rotation, and correction of the deformity occurred. On the right, pre- and postoperative photos.

CONCLUSIONS

It was concluded that the correction of deformities applying monoaxial screws in the convergent or divergent direction of the sagittal plane, with compression or distraction causing leverage force and vertebral rotation, is effective. We confirmed, using a statistical mechanical test, that the difference between pre- and post-fixation

Cobb degrees of the fixed synthetic spine segments was considered significant in both kyphosis and lordosis.

The author declare no potential conflict of interest related to this article.

CONTRIBUTION OF THE AUTHORS: Each author made significant individual contributions to this manuscript. EBG execution of surgeries, elaboration of the entire project. LFG, EBGJ, AS, VOM, JGC, and MFC data analysis, literature review. EBG, RGG, STG, intellectual concept.

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