NUMERICAL ANALYSIS OF SHORT AND LONG INSTRUMENTATION IN THE TREATMENT OF THORACOLUMBAR FRACTURES CONSIDERING THE LIGAMENTOUS PORTION

ANÁLISE NUMÉRICA DE INSTRUMENTAÇÃO CURTA E LONGA NO TRATAMENTO DAS FRATURAS TORACOLOMBARAES CONSIDERANDO PORÇÃO LIGAMENTAR

ANÁLISIS NUMÉRICA DE INSTRUMENTACIÓN CORTA Y LARGA EN EL TRATAMIENTO DE LAS FRACTURAS TORACOLUMBARES CONSIDERANDO LA PORCIÓN LIGAMENTARIA

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ABSTRACT

Objective: This study aims to numerically evaluate the surgical treatment of thoracolumbar fractures, comparing the strengths between the long and short fixations using the pedicle of the fractured vertebra, taking into account the supraspinous, intertransverse, and anterior longitudinal ligaments. Methods: A numerical analysis of the techniques of long and short fixation of a thoracolumbar spine fracture was performed using computed tomography images that were converted into three-dimensional models and analyzed through the ANSYS program. The two types of treatments were analyzed considering the tensions generated in the immediate postoperative period, when the fracture has not yet been consolidated. The anterior, posterior, supraspinal and intertransverse longitudinal ligaments were added, in addition to considering different vertebral geometries. Results: Taking into account that the maximum tensile stress of the material used in the metal implant, in the case of titanium, was 960 MPa, the highest tension found in the analysis of the short instrumentation was 346.83 MPa, reaching only 36.13% of the load the material supports, being, therefore, within a safety limit. The analysis performed in the spine with long instrumentation showed the highest tension value of 229.22 MPa. Conclusions: Considering the values found and the resistance of the synthesis material used, the short and long fixation can be considered in the treatment of thoracolumbar fractures with similarity and a good safety coefficient. ***Level of Evidence III; Case-Control.***

Keywords: Surgery / Spine; Fractures; Finite Element Analysis; Surgical Procedures; Operative.

RESUMO

Objetivo: Este trabalho tem como objetivo avaliar numericamente o tratamento cirúrgico das fraturas toracolombares, comparando a resistências entre as fixações longas e curtas usando o pedículo da vértebra fraturada, levando-se em conta os ligamentos supra-espinhal, intertransversal e longitudinal anterior. Métodos: Foi realizada uma análise numérica das técnicas de fixação longa e curta deumafratura da coluna toracolombar, utilizando-se imagens de tomografia computadorizada que foram convertidas em modelos tridimensionais e analisados através do programa ANSYS. Os dois tipos de tratamentos foram analisados considerando-se as tensões geradas no período pós operatório imediato, quando a fratura ainda não está consolidada. Foram adicionados os ligamentos longitudinal anterior, posterior, supra-espinhal e intertransversal, além de se considerar diferentes geometrias vertebrais. Resultados: Levando em consideração que a tensão máxima de ruptura do material utilizado no implante metálico, no caso o titânio, ser de 960 MPa, a maior tensão encontrada na análise da instrumentação curta foi de 346,83 MPa, atingindo apenas 36,13% da carga que o material suporta, estando, portanto, dentro de um limite de segurança. A análise realizada na coluna com instrumentação longa verificou o valor de tensão mais elevado de 229,22 MPa. Conclusão: Considerando os valores encontrados e a resistência do material de síntese utilizado, a utilização da fixação curta e longa podem ser consideradas no tratamento das fraturas toracolombares apresentando similaridade e um bom coeficiente de segurança. ***Nível de Evidência III; Caso-Controle.***

Descritores: *Cirurgia/Coluna Vertebral; Fraturas; Análise Elementos Finitos; Procedimentos Cirúrgicos Operatórios.*

RESUMEN

Objetivo: Este trabajo tiene como objetivo evaluar numéricamente el tratamiento quirúrgico de las fracturas toracolumbares, comparando las resistencias entre las fijaciones largas y cortas usando el pedículo de la vértebra fracturada, teniendo en cuenta los ligamentos supraespinal, intertransverso y longitudinal anterior. Métodos: Se realizó un análisis numérico de las técnicas de fijación larga y corta de una fractura de la columna toracolumbar, utilizando imágenes de tomografía computarizada que se convirtieron en modelos tridimensionales y fueron analizadas con el programa ANSYS. Los dos tipos de tratamiento fueron analizados considerando las tensiones generadas en el

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período postoperatorio inmediato, cuando la fractura aún no está consolidada. Se añadieron los ligamentos longitudinal anterior, posterior, supraespinal e intertransverso, además de considerar diferentes geometrías vertebrales. Resultados: Teniendo en cuenta que la tensión máxima de ruptura del material utilizado en el implante metálico, en el caso el titanio, fue de 960 MPa, la mayor tensión encontrada en el análisis de la instrumentación corta fue de 346,83 MPa, alcanzando apenas el 36,13% de la carga que el material soporta, estando, por lo tanto, dentro de un límite de seguridad. El análisis realizado en la columna con instrumentación larga mostró el valor de tensión más elevado de 229,22 MPa. Conclusiones: Teniendo en cuenta los valores encontrados y la resistencia del material de síntesis utilizado, la utilización de la fijación corta y larga puede ser considerada en el tratamiento de las fracturas toracolumbares presentando similitud y un buen coeficiente de seguridad. ***Nivel de Evidencia III, Caso-Controle.***

Descriptores: *Cirugía/Columna Vertebral; Fracturas; Análisis de Elementos Finitos; Procedimientos Quirúrgicos Operativos.*

INTRODUCTION

Thoracolumbar fractures have a variable distribution, however, most of these injuries affect the T12 and L1 vertebrae, up to 20% of which are burst type fractures.[1] There is a bimodal division related to the age of individuals with thoracolumbar fractures, whereby in young people there is a prevalence of fractures from high-energy traumas such as car accidents and falls from great heights, while the elderly are affected by low-energy traumas such as falls from one's own height.[2-4] The annual incidence of these fractures is about 13 out of every 100,000 inhabitants and is 2 times more prevalent in male than in female patients.[5]

There is no consensus around treatment of fractures in the thoracolumbar region. Some authors defend only posterior fixation, others only anterior access to the injured segment, while a combination of both anterior and posterior approaches has been indicated based on biomechanical studies.[6-8] The long assembly fixation method, involving the fixation of 2 to 3 levels above and below the fractured vertebra is the most classic technique used.[1,7,9,10] However, fixation of the fracture including the pedicles of the fractured vertebra and only one level above and below it has been shown to be a good alternative, economizing surgical time, causing less damage to the adjacent tissues, and generating less cost.[1]

The objective of this study is to numerically evaluate the surgical treatment of thoracolumbar fractures, comparing the resistance of long and short fixations using the pedicle of the fractured vertebra to thus be able to show that using the short fixation technique is viable and without risk of material failure.

METHODS

This study was approved by the Institutional Review Board of the Universidade de Passo Fundo. A model of the thoracolumbar spine was obtained from a male patient (80kg and 1.80m, without spine disease) from computed tomography images stored as Digital Imaging and Communications in Medicine (DICOM) files. In order for the geometric model to resemble reality, it was necessary to make a series of conversions and modelings in different software programs. The numeric simulation was performed using ANSYS *(*ANSYS, INC*)*. Vertebrae T11-L3 were considered for long fixation and vertebrae T12-L2 for short fixation. The modeling of three spinal ligaments was performed using Pro-Engineer (PTC, Inc.) three-dimensional modeling software. The modeled ligaments were the supraspinous ligament, the longitudinal anterior and posterior ligaments, and the intertransverse ligaments.

After modeling the ligaments of the spines obtained, several PTC software commands were used to generate new three-dimensional models, with dimensions 10% and 20% larger and 10% and 20% smaller than the initially modeled spine. The three-dimensional models were imported into the ANSYS software and a force of 1000N was applied to the upper vertebra of each set as surrounding conditions.

RESULTS

The analysis conducted on the spine with short arthrodesis and normal size presented the highest Von Mises theory stress value, 346.83 MPa, as can be seen in Figure 1.

In the spine with short arthrodesis and the three-dimensional model amplified 10% from the normal size, we confirmed that the highest Von Mises theory stress value was 333.96 MPa, as can be seen in Figure 2.

In the tests conducted on the spine with short instrumentation and the three-dimensional model reduced by 10% the highest Von Mises theory stress value was confirmed as 346.44 MPa, as seen in Figure 3.

In the 20% larger than normal size short instrumentation model the highest Von Mises theory stress value was confirmed at 263 MPa, as can be seen in Figure 4.

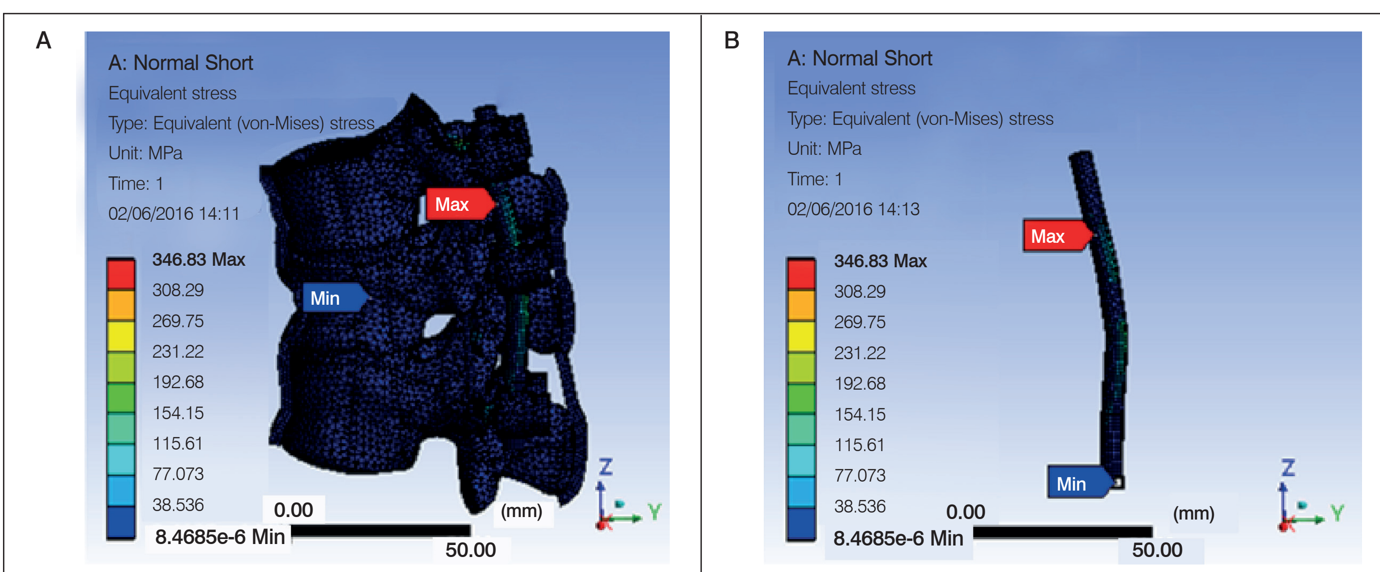

Figure 1. Analysis of the short instrumentation model and the point of maximum tension.

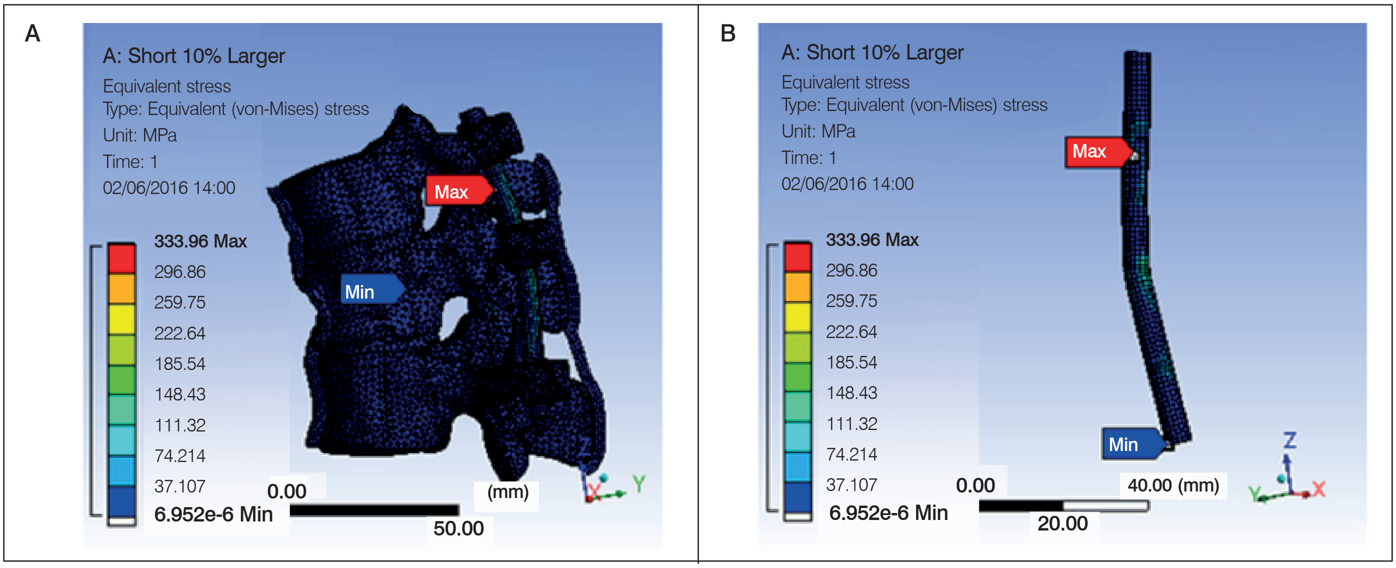

Figure 2. Analysis of the 10% larger short instrumentation model and point of maximum stress.

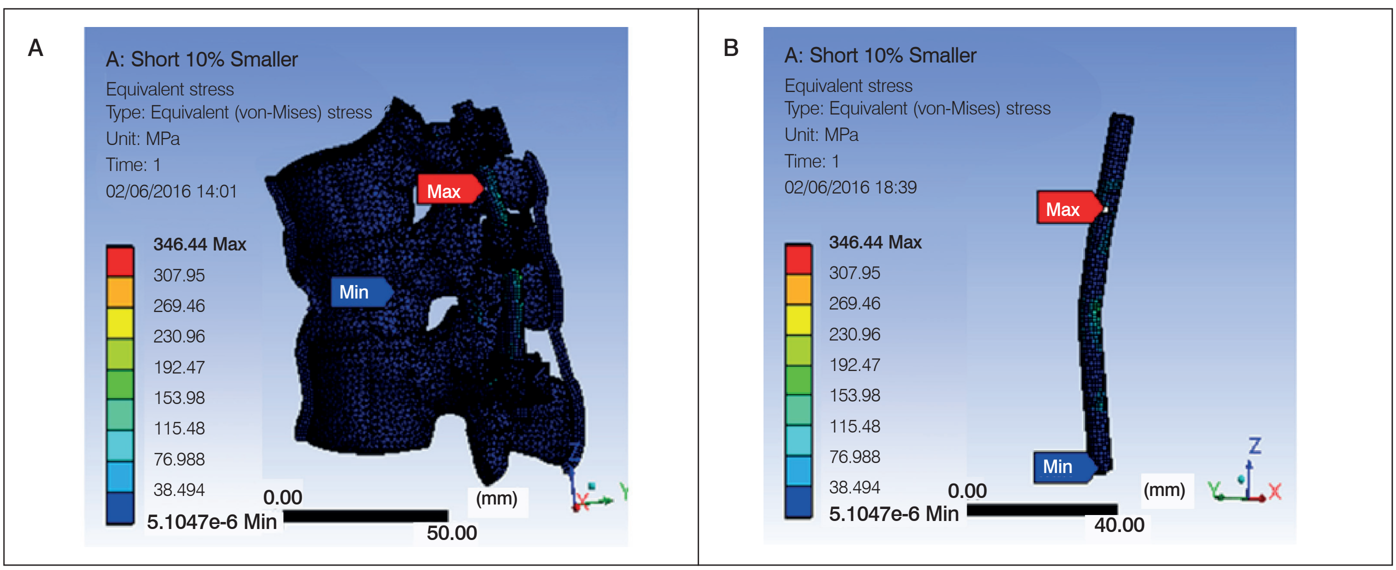

Figure 3. Analysis of the 10% smaller short instrumentation model and point of maximum stress.

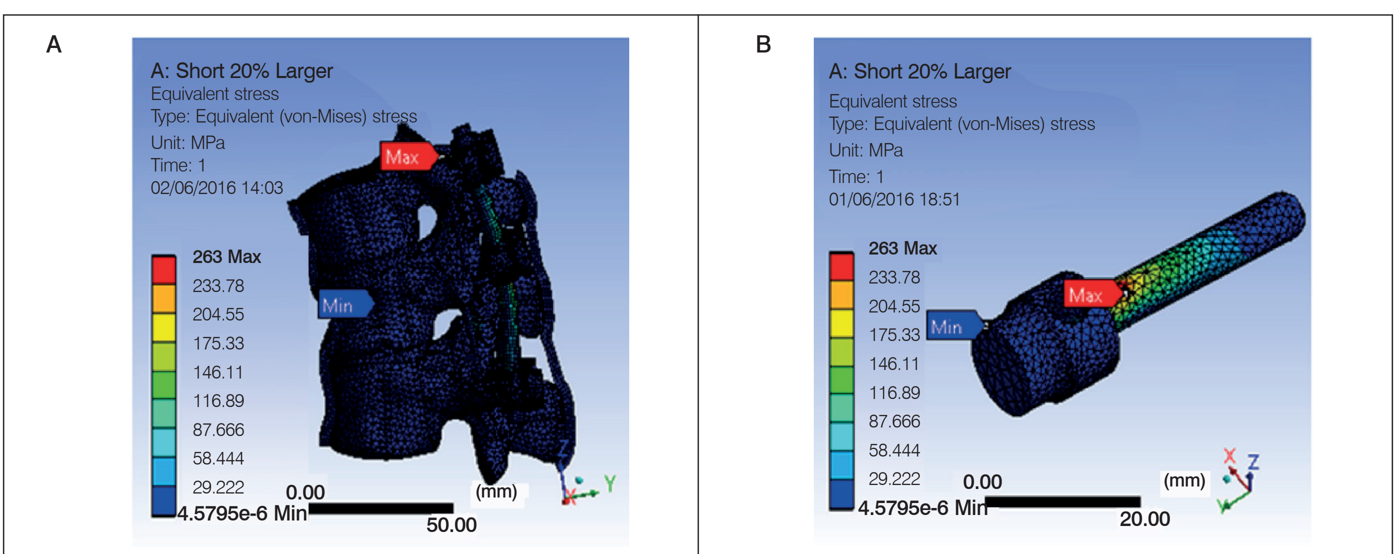

Figure 4. Analysis of the 20% larger short instrumentation model and the point of maximum stress.

In the 20% smaller than normal size three-dimensional model with the short fixation technique we confirmed that the highest Von Mises theory stress value was 330.77 MPa, as can be seen in Figure 5.

In the normal size model of the spine with long arthrodesis, the highest Von Mises theory stress value was 210.28 MPa, as seen in Figure 6.

The analysis conducted of the 10% larger three-dimensional model if the spine with long instrumentation presented a maximum Von Mises theory stress value of 220.2 MPa, as can be seen in Figure 7.

The analysis conducted of the 10% smaller three-dimensional spinal model with long instrumentation presented a maximum Von Mises theory stress value of 229.22 MPa, as per Figure 8.

In the 20% larger three-dimensional model with long instrumentation the highest Von Mises stress value was 180.96 MPa, as can be seen in Figure 9.

The last analysis was conducted on the 20% smaller three-dimensional spinal model with long instrumentation in which the highest Von Mises stress value was 181.29 MPa, as can be seen in Figure 10.

Table 1 presents a summary of the maximum stress values encountered, their location, and the relationship of the stress found to the limit of the material.

DISCUSSION

In this study, the surgical treatment of thoracolumbar fractures was numerically evaluated by the Von Mises theory, comparing long and short fixations in which the pedicle of the vertebral fracture was used. Several authors have presented numerical analyses of surgical thoracolumbar fracture fixation techniques, but none has studied the specific treatments approached in this study.

Hubner et al.[1] conducted a study in which two types of surgical treatments (long and short fixation) were clinically and radiographically evaluated and the authors concluded that there was no significant difference between the techniques used. Biomechanical studies suggest that performing fixation involving the pedicles of the fractured vertebra increase biomechanical stability.[11-14]

For degenerative diseases, several studies of anterior and posterior approach treatments were considered.[15,16] Liet et al. used numerical methods to evaluate short fixation both with and without the bilateral use of the pedicles of the fractured vertebra and concluded that the inclusion of the bilateral pedicles increased the resistance to stresses and reduced the stress in the fixation systems, in addition to optimizing the internal fixation, decreasing the incidence of synthesis failure.[17,18] Sun et al. evaluated surgical treatment of thoracolumbar

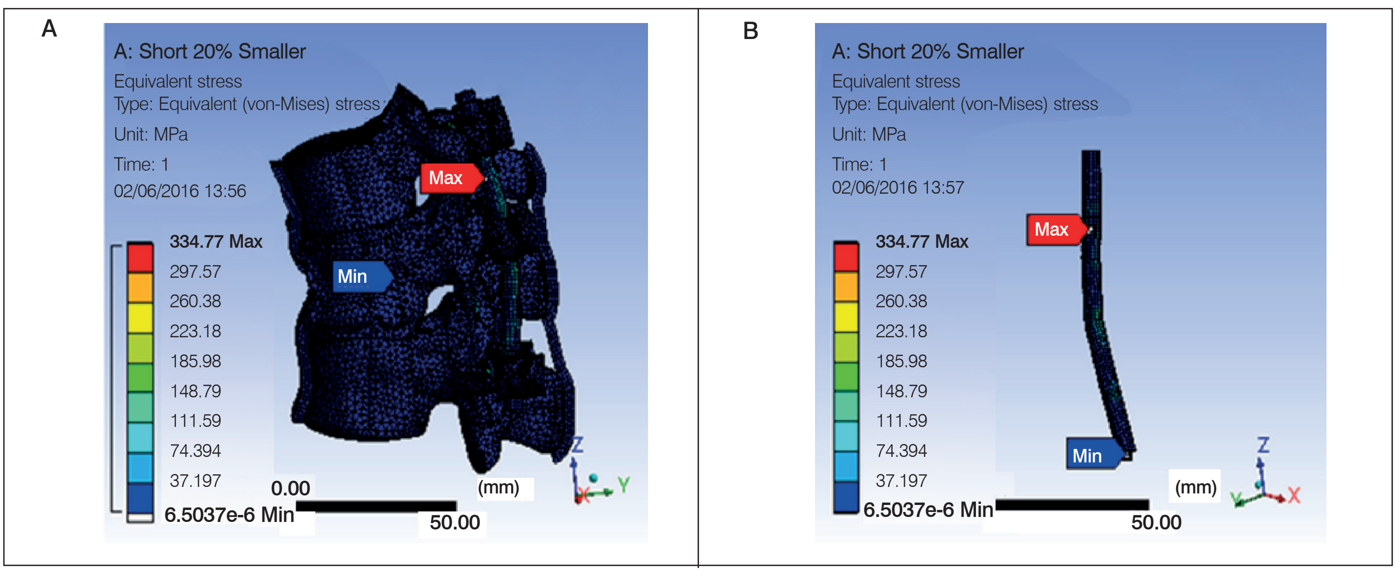

Figure 5. Analysis of the 20% smaller short instrumentation model and the point of maximum stress.

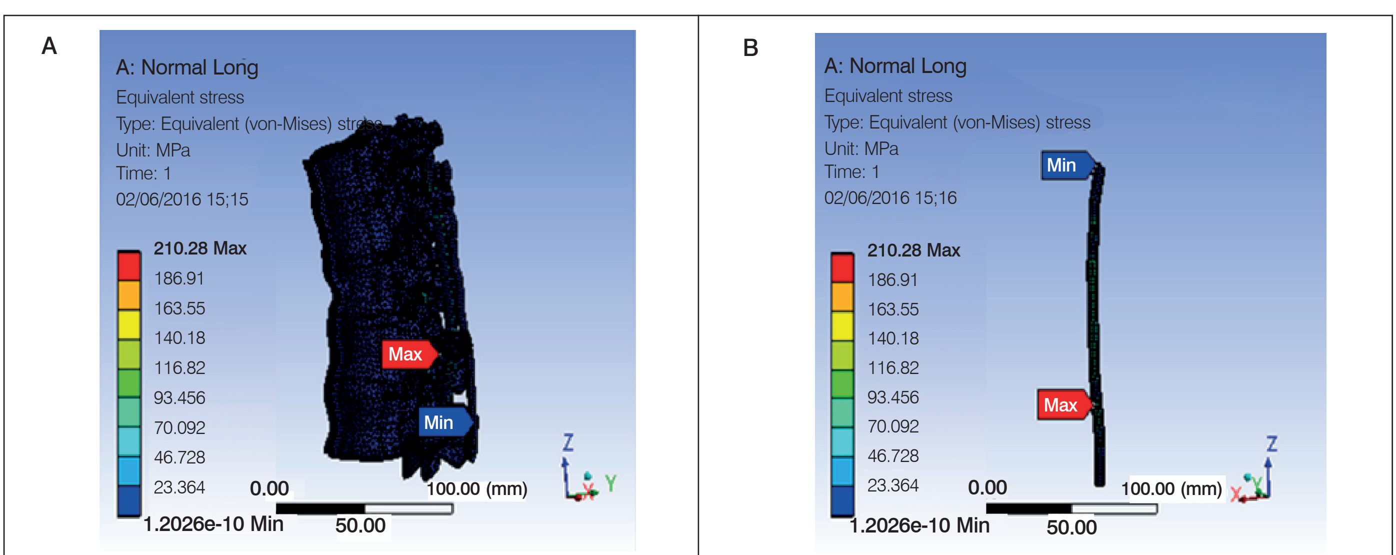

Figure 6. Analysis of the long instrumentation model and the point of maximum stress.

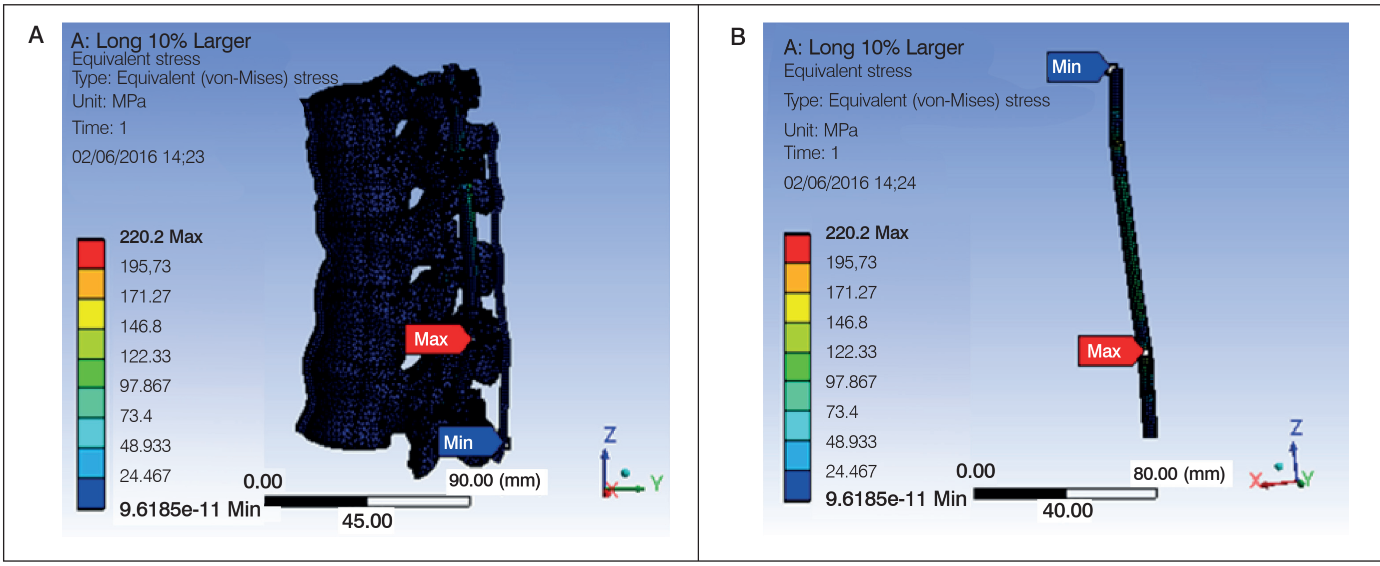

Figure 7. Analysis of the 10% larger long instrumentation model and the point of maximum stress.

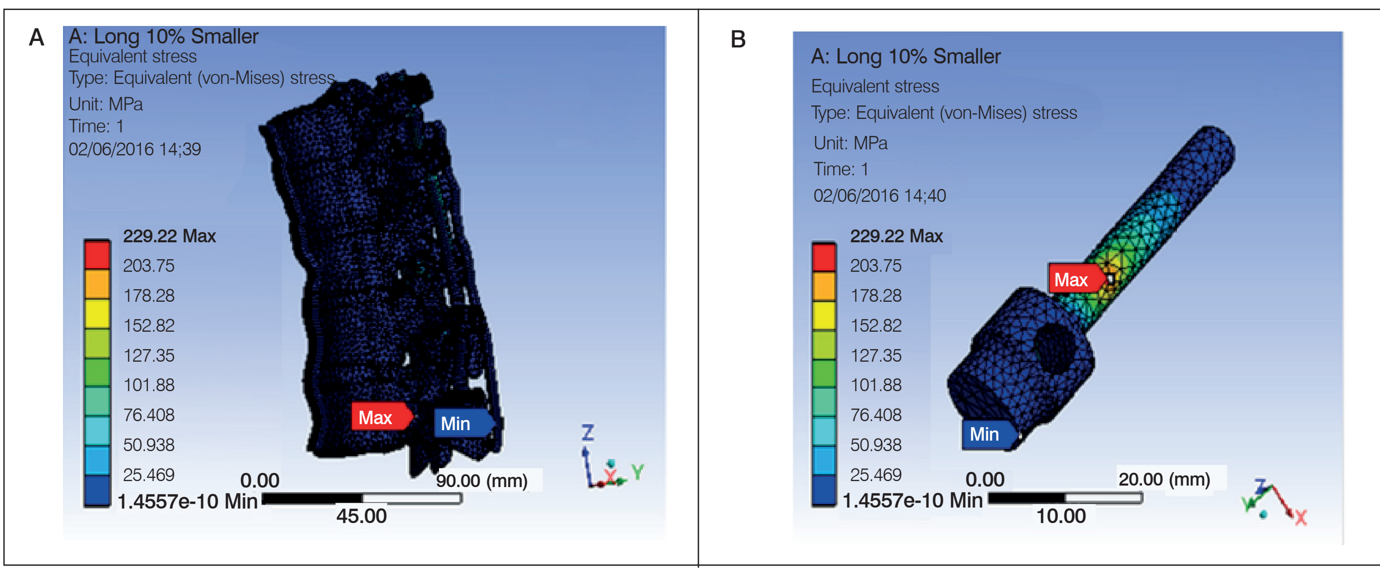

Figure 8. Analysis of the 10% smaller long instrumentation model and the point of maximum stress.

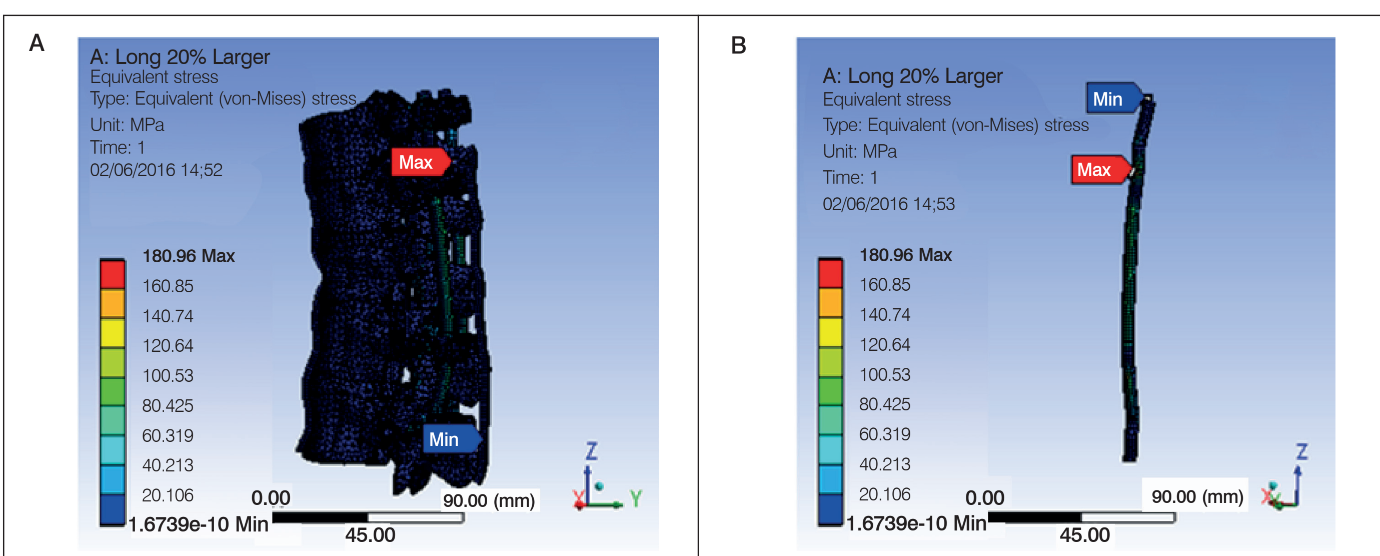

Figure 9. Analysis of the 20% larger long instrumentation model and the point of maximum stress.

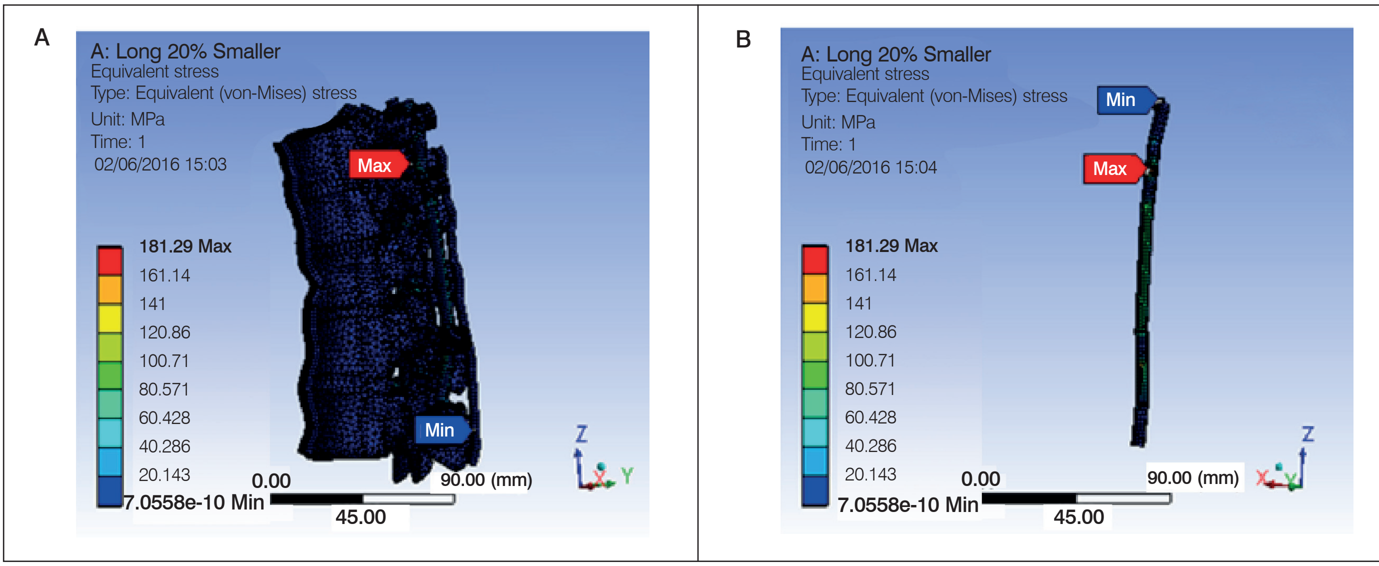

Figure 10. Analysis of the 20% smaller long instrumentation model and the point of maximum stress.

Table 1. Maximum stress, location, and percentage of force in relation to the resistance of the titanium observed in the analyses.

Analysis	Maximum Stress (MPa)	Location of point of maximum stress	Percentage of force analyzed in relation to titanium resistance
Short Normal	346.83	Rod	36.13%
Short 10% Larger	333.96	Rod	34.79%
Short 10% Smaller	346.44	Rod	36.09%
Short 20% Larger	263	Screw	27.40%
Short 20% Smaller	334.77	Rod	34.87%
Long Normal	210.28	Rod	21.90%
Long 10% Larger	220.2	Rod	22.94%
Long 10% Smaller	229.22	Screw	23.88%
Long 20% Larger	180.96	Rod	18.85%
Long 20% Smaller	181.29	Rod	18.88%

fractures with short fixation, including bilateral and unilateral pedicle screws in the fractured vertebrae, and observed similar clinical and radiographical results in the two groups.[19] Ouellet et al. conducted a biomechanical study comparing the resistance of instrumentation with divergent screws and with parallel screws using finite particles, synthetic models, and human cadavers and did not observe greater resistance in the assembly with divergent screws. [20] Other authors conducted biomechanical studies using numerical analysis of finite elements with different types of techniques, but none conducted a study comparing specifically long and short fixation including the pedicles of the fractured vertebra.[21-23]

Hübner et al.[7] studied the analysis of force applied to the metal in spinal instrumentation implants for the treatment of thoracolumbar fractures, analyzing long and short fixation techniques, but observed no considerable differences in the stress suffered by the synthesis in the two techniques. However, in their study they did not consider variations in the size of the patients or the soft parts such as the ligaments that are components of the structures that stabilize the spine.

In our study, we noted that in four of the five analyses of short instrumentation the highest stress is localized in the upper part of the rod. Only in the three-dimensional 20% larger model was the maximum stress localized on the screw. We also observed that, regardless of the size of the three-dimensional model analyzed, the highest stress was localized in the upper part of the metal implant. However, the location of maximum stress can change depending on geometry. The mean value of the maximum stress observed in the short analyses was 325 MPa.

On the other hand, the analyses of the long arthrodeses behaved differently. In two of the analyses conducted, the point of maximum stress was in the lower part of the rod. In another analysis, the point of maximum stress was located at a screw in the lower section, while in the two other analyses the point of maximum stress was found in the upper part of the rod. In the case of long arthrodesis, if we changed the size of the three-dimensional model, the points of maximum stress changed more easily than in the short models. This shows that short instrumentation may be more stable than long instrumentation, even though it has higher stress values. The mean value of the maximum stress found in the analyses with long instrumentations was 204.39 MPa.

Given that the maximum breakage stress of the material used in the metal implant is 960 MPa, in the case of titanium, and that the highest stress found in the normal short analysis was 346.83 MPa, reaching only 36.13% of what the material can support, this technique offers a good safety factor.

In this study, we used a three-dimensional model of the spine taking different sizes and some of the ligaments responsible for spine stability into account, but neither the musculature nor the various anatomical variations inherent to some patients were considered. The model used was of a normal vertebra with no underlying pathology, such as osteoporosis, such that perhaps a study addressing this is necessary to determine whether this technique can be safely used in elderly patients and those with osteoporosis. The maximum stress on the synthesis material did not even reach 50% of the resistance of the material, therefore variations such as bone with osteoporotic disease or increased force resulting from anatomical variations may not be sufficient to reach synthesis material limits. There is still room for new, more in-depth studies that address the theme in more detail.

CONCLUSION

Following the implementation of the longitudinal anterior, longitudinal posterior, supraspinous, and intertransverse ligaments and adding an analysis considering variations in the size of the model studied, no considerable change was observed between the stresses applied to the synthesis with the short and long techniques. We conclude that long and short fixation can be used safely in the treatment of thoracolumbar fractures.

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

CONTRIBUTION OF THE AUTHORS: Each author made significant individual contributions to this manuscript. DMR (0000-0003-2301-7924) was the main contributor to the writing of the manuscript. ARH (0000-0002-3374-5864), ED (0000-0001-6843-0988), DG (0000-0002-7224-8676), CLI (0000-0001-9422-2824), and LFS (0000-0001-8125-7104) evaluated the entire numerical analysis of the thoracolumbar fractures. DMR, ARH, and LFS performed the biographical research, reviewed the manuscript, and contributed to the intellectual concept of the study. DMR, DG, and ED evaluated the numerical studies of the diagnosis by tomography images. *ORCID (Open Researcher and Contributor ID).

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